The supporting databases and biological analyses for the revision of the Klamath Ocean Harvest Model

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Lloyd Goldwasser[1], Michael S. Mohr[1], Allen M. Grover[2], and Melodie L. Palmer-Zwahlen[2]

[1] National Marine Fisheries Service (NOAA)
Southwest Fisheries Science Center
Santa Cruz Laboratory
110 Shaffer Rd.
Santa Cruz, CA 95060

[2] California Department of Fish and Game
Marine Region
Ocean Salmon Project
1528 Healdsburg Ave.
Healdsburg, CA 95448

Table of Contents

List of Tables

List of Figures

Summary

This Technical Memorandum describes the revision of the databases and biological analyses that underlie the Klamath Ocean Harvest Model (KOHM). This model projects ocean populations, river run, harvest, and escapement levels of Klamath River Basin fall run chinook salmon (*Oncorhynchus tshawytscha*), and is one of the major tools used by the Pacific Fishery Management Council (PFMC) in determining the structure of the annual fishing season along the Pacific coast of the United States.

The KOHM uses as input age-specific abundance estimates for May 1 of the current year. It applies ocean harvest and impact rates (which depend on season structure, size limits, and shaker and dropoff mortality) to project the number of ocean fish that survive each month through the beginning of September. Age-specific maturation rates are then applied to the season's survivors to calculate the river run. River tribal and sport fishery impacts are deducted from the river run, and a specified fraction of the surviving fish are taken to spawn in natural areas. Existing policy constraints on the number of such naturally spawning fish usually guide the choices in season management. These management projections are performed annually, and look ahead no further than the current year.

The cohort analysis, which traces the history of each cohort individually, provides estimates of maturation, straying, harvest, and impact rates for the KOHM. This analysis in turn uses the proportion of fish of legal size as estimated by the size at age analysis, and the inriver age structure as estimated by the inriver age composition analysis. These analyses depend finally on data in the river coded-wire tag (CWT) database, the ocean CWT database, and the regulation database.

The need for revision of each link in this chain has been recognized for several years. In the new analyses described here, many of the parameter estimates are no longer overall averages, but are specific to each month, age, location, fishery, or release type. The expansion factors that convert CWT recoveries to total number of fish are now applied consistently. The integration of these results into a revised KOHM is expected for the 2002 management season.

Introduction

The Klamath Ocean Harvest Model (KOHM) is one of several models that are used by the Pacific Fishery Management Council (PFMC) in determining the structure of the annual fishing season along the Pacific coast of the United States. This model projects ocean populations, the river run, harvest, and escapement levels of Klamath River Basin fall run chinook salmon (*Oncorhynchus tshawytscha*), including production from Iron Gate Hatchery on the Klamath River and Trinity River Hatchery on the Trinity River.

The KOHM has been in use in some form since the late 1980s, and the need for a revision has been apparent for several years. In particular, the data upon which the KOHM is based had large numbers of errors, the model contained unnecessary simplifications, and the model was implemented as a spreadsheet. That implementation made annual updating and error checking cumbersome and unreliable. The revision was undertaken by members of the Klamath River Technical Advisory Team (KRTAT), an advisory body of the Klamath Fishery Management Council (KFMC). As we began the work, it became clear that the revision was not really a single project, but rather a cluster of separate yet interconnected projects. The revision of existing databases and creation of new databases are complete, as documented in this report. The age composition analysis, the size at age analysis, and the cohort analysis are complete or substantially complete, and this report documents them as well. The all stocks analysis, the effort analysis, the contact-effort analysis, and the implementation of the KOHM in a modern programming language still remain to be completed, and they will be described in a future report. Figure 1 shows the relationships among these projects and their place in the larger scheme.

Although not listed under the Federal Endangered Species Act, Klamath River fall run chinook salmon have continued to play an important role in shaping ocean fishing seasons. Ocean harvests of chinook must be constrained to meet the spawning escapement goal of Klamath River fall chinook (a floor of 35,000 spawners in natural areas, and a spawner reduction rate of no more than 67%), and to provide for the federally reserved fishing rights of the Yurok and Hoopa Valley Indian tribes (Pierce 1998). In 1993, those rights were determined by the Department of the Interior to amount to 50% of the total available harvest of Klamath River Basin salmon. There are additional sharing agreements between California and Oregon, and between ocean commercial and recreational fisheries. The PFMC uses a combination of dates, quotas, size limits, and bag limits in structuring the seasons to meet these constraints. However, neither size limits nor bag limits have been quantitatively modeled in the KOHM in the past; the work described here will allow size limits to be incorporated in the future.

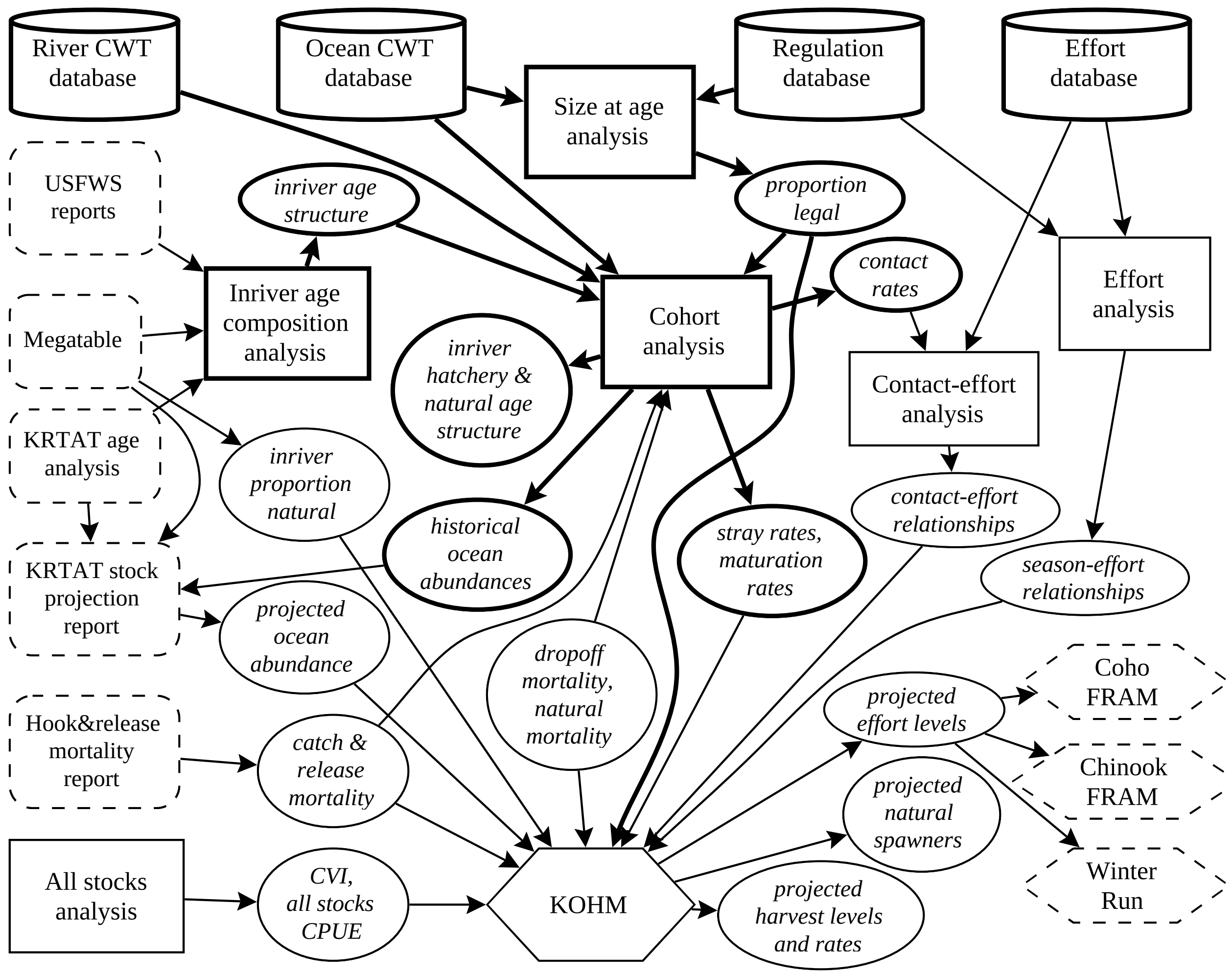

Figure 1. Overview of the projects associated with the revision of the Klamath Ocean Harvest Model, illustrating the complex flow of information required. Thicker outlines indicate components described in this report. Rectangles with rounded corners and dashed outlines represent sources of data used in the revision but not part of it; "cylinders" represent databases; rectangles with sharp corners represent analyses that are part of the revision; ellipses represent output and input quantities; hexagons represent models, either the KOHM or others that use its results but are not part of the revision. A similarly complex diagram could be drawn to illustrate the relationships among the databases and their sources.

Klamath Basin fall run chinook typically migrate from their natal stream to the ocean 60-150 days after hatching (Myers et al. 1998), although some hatchery fish are not released until they are yearlings or older. The fish then remain in the ocean, often traveling considerable distances either north or south, until they mature and return to fresh water to spawn, usually in their natal area. Maturation usually occurs during the third or fourth year of age, but can also occur in the second, fifth, or, rarely, sixth year. Males that mature at age 2 are referred to as jacks. The fish return to fresh water in August or September, and spawning takes place in October through December or January (Myers et al. 1998). Thus a given river run may contain adults from four different cohorts.

Salmon in the ocean are confronted by predators and other natural hazards, as well as commercial (primarily troll) or recreational (sport) fisheries. After entering the river, they may be harvested by sport or tribal fisheries before spawning; the history of the river fisheries is described by Pierce (1991a, 1991b). Most fish of hatchery origin are presumed to return to their natal hatchery to spawn, but some straying occurs.

A subset of hatchery fish are tagged by the clipping of their adipose fin and the insertion of a coded-wire tag (CWT) into their nasal tissues. The fin clip is intended to indicate the presence of the CWT, and the tag allows identification of the particular group of fish with which a recovered individual was released. Tag information is used in piecing together the history of the cohort and in estimating the effects of fisheries on the fish populations. In turn, information about hatchery fish is extrapolated to fish of natural origin.

The number of CWT fish recovered depends in part on the number of fish marked and released, the fraction of these fish that are legal-sized, and the dock-side sampling fraction. These fractions vary across time and area and thus must be accounted for in estimating total cohort abundance at age and to allow for meaningful comparisons across time and area. Four kinds of CWT recovery expansions are thus used in the analyses to account for: (1) sampling; (2) hatchery production; (3) contacts (versus harvest); and (4) impacts (versus harvest). The expansion for sampling converts the observed number of each CWT code collected during sampling to the number of tags with that code that would have been expected if all recoveries had been examined (a 100% sampling rate); it is specific to the sampling program at the time of recovery. The expansion for hatchery production converts the observed number fish of each CWT code to the total number of tagged and untagged fish from that release group; it is specific to the particular release code. The expansion for contacts converts the number of legal-sized fish that were harvested to the number of fish of all sizes that were contacted; it is specific to the month, the age and release type of the fish, and the minimum legal size limit in effect at the time of contact. The expansion for impacts converts the recoveries to total impacts, including harvest, hook-and-release mortality, and dropoff mortality; it is also specific to month, age and release type of the fish, and the minimum size limit in effect at the time of contact.

Scale analysis provides another means of identifying fish age, and can be applied to fish of natural as well as hatchery origin. Scale analysis is less accurate than CWTs, which can provide an unambiguous identification of an individual's age, but a method for correcting scale ageing bias exists (Kimura and Chikuni 1987). Scale analysis is used here to determine the age-composition of the in-river run in each year.

As Figure 1 indicates, the application of our analyses to the databases provides estimates of population- and fishery-related parameters, and these estimates constitute the biological foundation for the revision of the KOHM.

Databases

Model analyses and conclusions based on them depend on the reliability of the data, so revision of the databases provides the foundation of this work. Considerable effort and attention went into uncovering and correcting errors and inconsistencies in the data, and as a result there have been substantial improvements in the completeness and reliability of the datasets. The new format will also facilitate the annual updating of the databases with the current season's data.

There exists some debate among fishery managers regarding the existence of a late fall chinook run in the Klamath Basin, and 22 release groups have been labeled as such. However, the validity of this distinction is still uncertain, and, accordingly, we treat all fish in question as fall run.

Ocean Coded-Wire Tag (CWT) databases

Release information

The database KOHM_REL.dbf (338 records) is the database containing the "master" list of all fall chinook CWT release groups tagged in the Klamath and Trinity River basins from 1976 through 1999. Each hatchery *release group* (also called a tag group) has been assigned to one of nine general *release types*, based on origin (hatchery or wild) and life history stage at release; a release group can contain one or several CWT release codes. Table 1 shows these release types.

Release stages were determined by fish weight and time of release. Most fingerlings weigh less than 13 g and are released during spring; yearlings generally weigh much more, and are released the following fall. Fish held for over a year and released during late winter-early spring are considered "yearling plus."

Information for each CWT release group was thoroughly checked for missing or misreported data. In several cases, large groups of fish were tagged with several CWT codes, yet the production factor (total number of fish released / total number tagged) had been applied to only one CWT code, with no expansion given for the other codes. These and other cases were corrected so that the appropriate production factor is associated with each CWT code.

This database is linked to all ocean and inland recovery files to add pertinent information, such as release group, brood year, and production factor, which is used in both the cohort reconstruction and the KOHM.

Table 1. The release types in the ocean CWT database. In some years hatchery-derived fish are released outside either hatchery (XHAF and XHAY).

Release type	Source	Release stage	Number of release groups
IGHF	Iron Gate Hatchery	fingerling	56
IGHY	Iron Gate Hatchery	yearling	48
TRHF	Trinity River Hatchery	fingerling	46
TRHY	Trinity River Hatchery	yearling	41
TRHZ	Trinity River Hatchery	yearling plus	6
XHAF	Extra-Hatchery Production	fingerling	8
XHAY	Extra-Hatchery Production	yearling	63
Wild	Wild Stock captured and tagged	(any)	57
Deleted	CWT release not used because run designation not known or definite	(any)	13

Recovery data

Records of all Klamath CWTs recovered on the west coast since 1978 are downloaded from the Pacific States Marine Fisheries Commission's Regional Marking Information System (RMIS) (Johnson 1990, RMPC 1997) into ALLKOHMREC.dbf. Several programs and databases, operating on ALLKOHMREC.dbf in a series of steps, are used to create the ocean recoveries database (ALLOCEANREC.dbf) and the database containing recoveries from all other river basins (OTHERRIVERREC.dbf); both of these databases are needed for the analyses. In ALLOCEANREC.dbf, each CWT recovery is assigned a KOHM area based on the sample/catch area where it was originally collected, and this is the area the KOHM uses to determine fishery impacts. Several programs and databases, operating in a series of steps, are used to create the ocean and other river basin recovery databases needed for the analyses. Appendix 1 details the flow of information from one database to another, and the actions of the programs that handle that flow.

Ocean CWT data are collected and organized in the geographic areas shown in Table 2. The KOHM has treated the SOC as a single unit in the past, while the smaller subdivisions have been used as separate management units. Matching the model structure and the management units may help improve the outcomes of both parts of the process.

Table 2. The KOHM areas and major ports, and the geographic boundaries between them. NOR=NO=Northern part of Oregon; NORN=northern part of NOR; NORS=southern part of NOR; COS=CO=Coos Bay; KMZ=KZ=Klamath Management Zone; KMZO=Oregon part of KMZ; KMZC=Californian part of KMZ; FTB=FB=Fort Bragg; SOC=southern part of California; SF=San Francisco; MO=Monterey.

KOHM area	Major port	Sample / Catch area
NOR	NO	north of Heceta Head
NORN	NO	north of Cape Falcon
NORS	NO	between Cape Falcon and Heceta Head
COS	CO	between Heceta Head and Humbug Mtn. (Cape Blanco)
KMZ	KZ	between Humbug Mtn. (Cape Blanco) and Horse Mtn.
KMZO	KZ	between Humbug Mtn. (Cape Blanco) and CA/OR border
KMZC	KZ	between CA/OR border and Horse Mtn.
FTB	FB	between Horse Mtn. and Pt. Arena
SOC	SF,MO	south of Pt. Arena
SOC1	SF	between Pt. Arena and Pt. Reyes
SOC2	SF	between Pt. Reyes and Pt. San Pedro
SOC3	SF	between Pt. San Pedro and Pigeon Pt.
SOC4	MO	between Pigeon Pt. and Pt. Sur
SOC5	MO	south of Pt. Sur

Regulation database

The regulations database, OCEANREGS.dbf, was created by compiling all ocean chinook fishery regulations in effect since 1978 by KOHM area, by date, by fishery (primarily commercial troll and sport), and by minimum size limit (PFMC 2000). The programs GETKOHMAREA.prg and GETLIMIT.prg use this database respectively 1) to determine whether the default KOHM area was actually open on the given sample date; and 2) to obtain the minimum size limit in effect on the sample date. If either program encounters a problem, it flags the record for user intervention.

All flagged records were reviewed, given a correct KOHM area, and placed in FIXEDKOHM.dbf (n=437) so that the problem will be corrected automatically with future downloads. Ultimately, the corrections will be incorporated in the server databases, but in the meantime this method avoids the need to correct a record manually more than once.

Appendix 1 provides further details about this database.

Effort database

The catch/effort database, CATCH_EFFORT.dbf, consists of the number of chinook salmon landed and days fished by fishery in both Oregon and California. Sport effort is measured in angler-days fished, while commercial effort is in boat-days fished. Previously, CDFG estimated the number of days fished in the commercial fishery, $\hat{f}$, using a mean-per-unit estimator:

$$\hat{f} = \bar{f}_{deliv} \cdot N_{deliv} \tag{1}$$

where $\bar{f}_{deliv}$ is the average number of days fished per sampled delivery and N_{deliv} is the number of deliveries. However, large and small boats may have been sampled at different rates, which would bias this estimate because larger boats tend to stay out for longer periods. To avoid this potential bias, we used a second method, under consideration by the CDFG, which scales effort directly by the number of salmon landed. Using all CDFG catch and sample data from 1978 through 1999, we estimated commercial effort using a ratio estimator:

$$\hat{f} = \frac{\bar{f}_{deliv}}{\bar{l}_{deliv}} \cdot \hat{L} \tag{2}$$

where, for each month and major port area, $\bar{l}_{deliv}$ is the mean number of salmon landed by sampled boats and $\hat{L}$ is the estimated total number of salmon landed. Total fishing effort by month and KOHM area can then be calculated by summing the effort at each major port in the area. For example, the troll effort in May in the KMZ would be the sum of the effort in May in Oregon's KMZO major port and California's KMZC major port (Eureka and Crescent City).

Since catch-sample databases were often "cut and pasted" together during the early 1980s, some of these data did not directly match the catch or the effort report in the Fishery Review (PFMC 2000). For instance, for reporting purposes, catch and samples taken in a closed port were often added by hand to the nearest open port. Several programs were written to process these original catch/sample data into a database that would 1) make them comparable to the Review totals, and 2) allow a direct comparison of the two estimators used to determine days fished. Further details about the effort databases are in Appendix 1.

Inland CWT database

An inland CWT database, KOHM_INLAND.dbf, was created for all Klamath fall chinook CWTs recovered by Klamath and Trinity River recreational and tribal harvest monitoring programs. Since 1979, the California Department of Fish and Game (CDFG) has conducted sampling programs to monitor the sport harvest on the Klamath and Trinity Rivers. These programs have also documented the recoveries of CWTs from spawning grounds and both Iron Gate and Trinity River hatcheries. Each year, CDFG submits an annual summary of all CWT recoveries to the Klamath River Technical Advisory Team.

Tribal net monitoring was conducted by the U.S. Fish and Wildlife Service (USFWS) for the Hoopa Valley Tribe (HVT) from 1980 to 1982 and for the Yurok Tribe (YT) from 1980 to 1993. In 1983, HVT began monitoring their Trinity River chinook net harvest, and YT started their own program on the Klamath River in 1994. All recovery data collected by the USFWS during 1980-1987 and 1989-1993 were obtained from annual reports by the Klamath River Fisheries Assessment Program (USFWS). Recoveries during 1988 were downloaded directly from RMIS. Tribal net CWT recoveries were taken directly from summary spreadsheets submitted by the respective fishery departments of the HVT and YT.

Appendix 1 provides further details about this database.

Age composition analysis

The age composition analysis gives an estimate of the proportion of each age class among the fish that matured and entered the Klamath River. This information is used in the cohort analysis to apportion the components of each year's run into cohorts so that the history of each cohort can be reconstructed. The age composition analysis does not distinguish among hatchery and natural fish (which are taken to be fish that were born outside of hatcheries); the cohort analysis uses additional CWT information and analytical techniques to separate fish by origin.

Methods

Because of differences in the source or quality of the data, different methods were used for different periods (1979-1990, 1991-1996, and 1997-1999) to derive the age composition of each in-river run; the methods used for each period are described below. Except in a few cases, the starting point is the estimated numbers of jacks and adults in the Megatable (CDFG 2000), which contains the estimate of the size of the river run for each year, broken down by location and fishery, but does not separate the adult age classes. The general approach in calculating the age composition is to derive the number of age 3, age 4, and age 5 fish in each run by multiplying the total number of adults (from the Megatable) by some estimate of their relative proportions (usually obtained from a series of USFWS studies that took place from 1981–1991, or from KRTAT reports). The number of jacks is usually taken directly from the Megatable.

The period 1979-1990

The method that had previously been used for 1979-1983 has now been applied through 1990. This method uses the age composition estimates based on analyses of scale samples from beach seining at the mouth of the Klamath River, as described in a series of USFWS reports (USFWS 1981–1989, 1991–1992). Although beach seining results have been available for 1984-1990, the previous analysis in the COHORT spreadsheet had used a different method because of concerns that the beach seining technique might bias the age estimates. Appendix 2 examines both the methods and the results in detail, and shows that the method based on beach seining and scale analysis (1) has no apparent age bias; (2) is more consistent both internally and in relation to other data than is the previous method; and (3) is considerably easier to understand than is the previous method.

Beach seining at the mouth of the Klamath River was discontinued after 1990, so this method is not possible for subsequent years.

The period 1991-1996

The age composition estimates for 1991-1996 were adjusted from earlier estimates only to reflect the addition of relatively small numbers of fish to the Megatable. The adjustments maintained the previous location- and fishery-specific proportions of adults (based on scale analysis and published in the USFWS reports), while conforming to the new Megatable totals (rounding occasionally introduced discrepancies of single fish). Because the proportions of each age class differ among locations and fisheries, and there were changes for only a few of the locations or fisheries, the overall proportions may differ slightly from earlier estimates.

The period 1997-1999

Current age composition estimates for 1997-1999 already exist, including adjustments by the KRTAT for the final estimates of the total number of fish, and we accordingly use these estimates without modification. For some locations or fisheries, the number of jacks is not identical to that given in the Megatable. Documentation of these revisions already exists.

Results

Table 3 shows the age composition of the river run of Klamath River fall chinook for 1979-1999. Counts and proportions both vary considerably from year to year.

Prospects

In the future, the construction of the Megatable and the KRTAT age analysis will be performed as a joint process, and a single document will be produced annually that will provide the estimate of the age composition of the in-river run. This estimate will then be used directly in the cohort analysis and the KOHM, thus eliminating the need for a separate age composition analysis.

Table 3. Klamath River fall run chinook, age composition of river run for 1979 - 1999.

Run year	Estimated counts, at age				Adults	Totals	Percentages, at age			
	2	3	4	5			2	3	4	5
1979	11,665	19,618	27,872	3,708	51,199	62,864	18.6	31.2	44.3	5.9
1980	36,764	19,306	20,716	5,532	45,554	82,318	44.7	23.5	25.2	6.7
1981	28,110	63,953	14,318	1,790	80,061	108,171	26.0	59.1	13.2	1.7
1982	39,391	30,018	33,864	2,627	66,509	105,900	37.2	28.3	32.0	2.5
1983	3,845	35,840	20,725	924	57,490	61,335	6.3	58.4	33.8	1.5
1984	8,277	21,669	24,378	1,083	47,131	55,408	14.9	39.1	44.0	2.0
1985	69,374	32,914	25,638	5,803	64,356	133,730	51.9	24.6	19.2	4.3
1986	44,530	162,742	29,819	2,274	194,836	239,366	18.6	68.0	12.5	1.0
1987	19,043	89,567	112,425	6,764	208,756	227,799	8.4	39.3	49.4	3.0
1988	24,048	101,035	86,369	3,870	191,274	215,322	11.2	46.9	40.1	1.8
1989	9,097	50,285	69,436	4,299	124,020	133,117	6.8	37.8	52.2	3.2
1990	4,389	11,598	22,910	1,302	35,810	40,199	10.9	28.9	57.0	3.2
1991	1,755	10,839	20,717	1,041	32,598	34,353	5.1	31.6	60.3	3.0
1992	13,688	7,331	18,333	994	26,658	40,346	33.9	18.2	45.4	2.5
1993	7,597	48,383	8,102	658	57,143	64,740	11.7	74.7	12.5	1.0
1994	14,368	35,672	25,046	850	61,568	75,936	18.9	47.0	33.0	1.1
1995	22,769	194,098	17,554	2,073	213,725	236,494	9.6	82.1	7.4	0.9
1996	9,529	39,049	136,325	0	175,374	184,903	5.2	21.1	73.7	0.0
1997	7,992	34,872	44,183	4,595	83,650	91,642	8.7	38.1	48.2	5.0
1998	4,639	58,744	30,149	1,678	90,571	95,210	4.9	61.7	31.7	1.8
1999	19,096	29,427	20,154	1,324	50,905	70,001	27.3	42.0	28.8	1.9

Size-at-age analysis

The size at-age-analysis gives an estimate of the size distribution of ocean fish for each month and age class, and is based on the revised database of ocean CWT recoveries between 1979 and 1999. These distributions, in combination with a minimum size limit for legally caught fish, provide estimates of p_{legal}, the proportion of fish of each age that are of legal size during a given month. This information is used in the cohort analysis to expand harvests (the total catch) to contacts (all fish that were brought to the boat, including sublegals that were released), and in the KOHM to project harvests from contact rates.

In the past, both the cohort analysis and the KOHM have assumed the proportion of fish of legal size to be an age-specific constant, regardless of the actual size limit, the month of the year, or particular characteristics of the fish. That simplification has made it impossible, when shaping a fishery, to assess the effect of shifting its legal size limit. Working with the actual size distribution makes it possible to use the size limit quantitatively as a management tool.

Methods

The size-at-age analysis uses data from the Ocean Recoveries CWT database, expanded for sampling and production. The database and analysis distinguish between fish of different hatchery release types, implicitly extrapolating to natural fish. We excluded four groups from these analyses: (1) fish that were below the minimum size limit in effect at the time of capture (633 recoveries; see below); (2) fish from hatchery release types labeled as “Wild” or “Deleted” in the database (257 recoveries); (3) fish recovered before 1979 (3 recoveries); and (4) fish listed as having an age greater than 6 (1 recovery). A total of 22,288 recoveries remained, giving relatively large sample sizes for our analyses.

Rather than estimate a size distribution for age 6 fish, of which there were 10 in the entire database (Table 4), we simply use a proportion legal = 1.0 for those few instances in which they appeared in the cohort analysis. Most groups of age 5 fish have the same proportion legal, so this assumption for fish of age 6 is reasonable. The KOHM includes only ages 3 through 5, so more elaborate treatment of age 6 fish was not necessary.

The cohort reconstruction analysis requires estimates of size-at-age for all recovered fish, even when only a single fish was recovered, but it did not require estimates for months in which no fish were recovered. In contrast, the KOHM might be used to generate projections for any kind of fishing season, no matter how unlikely, so it requires estimates of the proportion legal for all ages in all months of the year. As described below, we accordingly generated estimates for all months, including those for which the sample size was zero.

The analysis assumed a normal size distribution, and provided estimates of the mean length and standard deviation in length. One major statistical issue in this analysis is that the recoveries represent only a truncated subset of the size distribution of the population. Fish below the legal size limits were rarely retained, and are represented in the database by only a relatively small number of records. Consequently, simple statistics of the recovered fish would overestimate the actual mean and underestimate the standard deviation of the whole population. We avoided these biases by using maximum likelihood methods to estimate the most likely normal distribution from which the fish were drawn, given the observed sizes and the size limit in effect at the time of capture. Figure 2 illustrates the relation between the observed distribution and the estimated distribution.

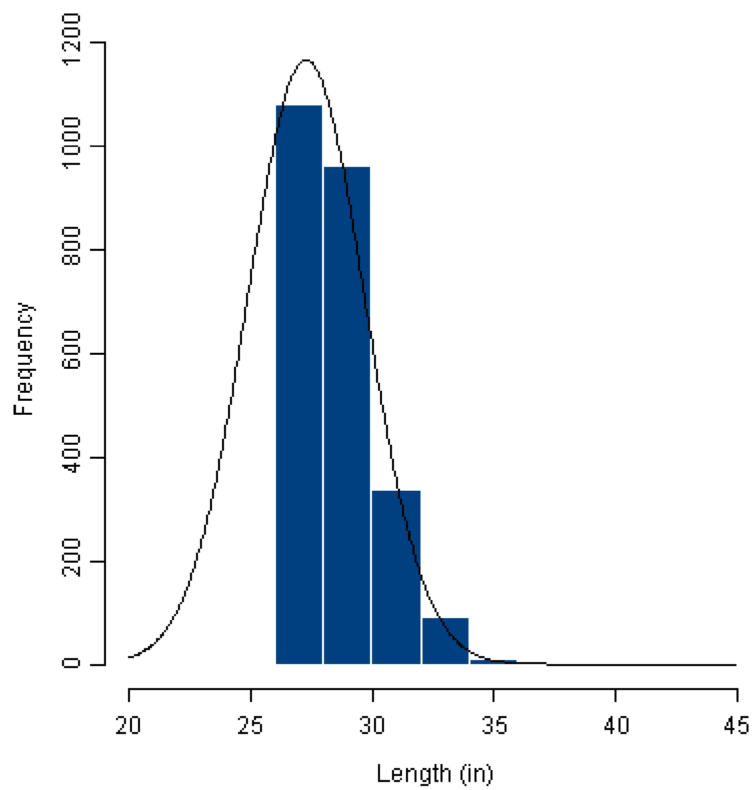

Figure 2. The relationship between the observed size distribution (bars) and the estimated size distribution (curve), given a minimum legal size limit of 26 inches. Because of the size limit, part of the distribution is not visible to sampling, but maximum likelihood methods allow the entire distribution to be estimated. The technique is slightly more powerful than suggested here, because it can associate with each fish the minimum size limit in effect at the time of its capture, instead of assuming a uniform size limit on fish captured in disparate years or locations.

The models estimated the mean length and standard deviation in length for each month and age class separately. An ideal analysis would distinguish additionally between the distributions for fish of different release stage (fingerling, yearling, or yearling plus), basin (Klamath or Trinity), gear or fishery (troll or sport), location (from the northern Oregon cell to the southern California cell), and year (from 1979 to 1999). Tables 4 - 10 show the breakdown of recoveries into these categories; note that some groups have small sample sizes, especially when the recoveries are separated into more than one type of category. Thus, although an analysis that included all these factors simultaneously might provide a great deal of information about the relationships among spatial and temporal trends, life history, and fisheries, the sample sizes would not yield valid estimates with so many fine distinctions simultaneously. Even if such an analysis were possible, the complexity of detail might obscure important features rather than clarify them.

Table 4. Ocean CWT recoveries, by age.

2	3	4	5	6		Total
208	13,099	8,845	126	10		22,288

Table 5. Ocean CWT recoveries, by month.

Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
1	7	35	2844	4648	6929	6059	1492	272	1

Table 6. Ocean CWT recoveries, by year.

1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
340	1017	1473	2614	1110	311	1297	4003	4621	2324	1517
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
	593	161	36	85	63	276	277	61	42	67

Table 7. Ocean CWT recoveries, by release type. The types IGHF and IGHY are from Iron Gate Hatchery; TRHF, TRHY, and TRHZ are from Trinity River Hatchery; XHAF and XHAY were offsite releases. Codes ending with “F” represent fingerling releases, those ending with “Y” represent yearling releases, and those ending with “Z” represent yearling-plus releases.

IGHF	IGHY	TRHF	TRHY	TRHZ	XHAF	XHAY
2039	5653	4409	6430	2792	68	897

Table 8. Ocean CWT recoveries, by fishery and KOHM area. NOR=Northern Oregon; COS=Coos Bay; KMZO=Klamath Management Zone, Oregon part; KMZC=Klamath Management Zone, California part; FTB=Fort Bragg; SOC=southern part of California.

	NOR	COS	KMZO	KMZC	FTB	SOC	Total
Troll	1188	6414	3119	3886	3614	1505	19726
Sport	102	209	1196	845	104	106	2562
Total	1290	6623	4315	4731	3718	1611	

Table 9. Ocean CWT recoveries, by KOHM area and month. Area codes as in Table 8.

	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
NOR	0	0	6	107	75	347	453	149	153	0
COS	0	0	1	239	418	2706	2585	636	38	0
KMZO	0	0	0	389	827	1020	1627	370	81	1
KMZC	0	0	0	1174	1519	812	944	282	0	0
FTB	0	0	4	668	1205	1479	318	44	0	0
SOC	1	7	24	267	604	565	132	11	0	0

Given the difficulty of analyzing the size distribution by all categories simultaneously, we tailored the size-at-age analyses to its intended targets, the cohort analysis and the KOHM. Our baseline analysis did not distinguish between any categories other than age and month. The cohort analysis distinguishes between both basin (Klamath, Trinity) and release stage (fingerling, yearling, yearling plus) within the hatchery portion of each cohort, and we accordingly calculated estimates of the size distribution for each release type, which combines basin and release stage. In contrast to the cohort analysis, the KOHM itself does not distinguish among release types, because the proportion of Klamath and Trinity fish among the natural fish in the ocean is not known and the distinctions among hatchery release types are not relevant. However, differences between fisheries (troll, sport) are important because the KOHM is the tool for shaping the season for both sport and troll fisheries. Accordingly, we also ran analyses that estimated means and standard deviations by fishery for each age and month.

Table 10. Ocean CWT recoveries, by KOHM area, month, and fishery. Area codes as in Table 8.

Troll	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**
NOR	0	0	6	105	61	313	407	143	153	0
COS	0	0	1	235	387	2600	2533	620	38	0
KMZO	0	0	0	381	653	634	1165	207	78	1
KMZC	0	0	0	1140	1323	399	774	250	0	0
FTB	0	0	0	664	1154	1441	311	44	0	0
SOC	0	0	6	250	578	538	123	10	0	0
Total	0	0	13	2775	4156	5925	5313	1274	269	1

Sport	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**
NOR	0	0	0	2	14	34	46	6	0	0
COS	0	0	0	4	31	106	52	16	0	0
KMZO	0	0	0	8	174	386	462	163	3	0
KMZC	0	0	0	34	196	413	170	32	0	0
FTB	0	0	4	4	51	38	7	0	0	0
SOC	1	7	18	17	26	27	9	1	0	0
Total	1	7	22	69	492	1004	746	218	3	0

Preliminary analyses compared the relative strengths of these and several other models. The alternative models estimated size distributions with the data classified by release stage, basin, and fishery separately, and by the combinations <release stage x basin>, <release stage x fishery>, <basin x fishery>, and <release stage x basin x fishery>. The comparisons were based on the Akaike Information Criterion (Burnham and Anderson, 1998), an index that balances the log likelihood of a best-fit model and the number of parameters that the model employs in explaining the variation in the data. Specifically, the log-likelihood value, ℓ, for a given model was calculated as

$$\ell = \sum_{\text{recoveries}} w \cdot \log\left(\frac{\phi(l;\mu,\sigma^2)}{1-\Phi(sl;\mu,\sigma^2)}\right), \tag{3}$$

where w is the weighting of each recovery for production and sampling, l is measured length of the recovery, sl is the size limit in effect at the time of its capture, and $\phi(\cdot;\mu,\sigma^2)$ and $\Phi(\cdot;\mu,\sigma^2)$ are, respectively, the normal (gaussian) probability density distribution and cumulative probability distribution with mean μ and variance σ^2. Then the Akaike index for the model was calculated as

$$AIC = -2\ell + 2 \cdot P, \tag{4}$$

where P is the number of independent parameters in the model. The lower the value of AIC, the better the score for the model. Each model was evaluated over the whole dataset, with the most likely mean and standard deviation estimated independently for each month and age. For almost all months and ages, models of <release stage x basin> performed better than did models of either release stage or basin separately. The preferred model, according to the comparisons, was usually the most complicated one, <release stage x fishery x basin>, but the length estimates it provided had an undesirable level of month-to-month variability due to small sample sizes.

The maximum likelihood method was not robust to small sample sizes when the mean size of fish in the population was well below the size limit. In some cases, small variations in the number of fish caught just above the size limit had a large effect on the mean of the estimated distribution, and we encountered a few instances (usually with age 2 fish) in which the estimate of the mean size was clearly incorrect for this reason. Even without the obvious inaccuracy, we would usually have excluded these estimates from our analysis on the basis of the small sample sizes alone.

In general, sample sizes of at least 20 were necessary for a good estimate of the size distribution for a given age in a given month. Only ages 3 and 4 have large enough sample sizes consistently to yield reliable estimates of the size distribution; outside of the main part of the season (May to September), the sample sizes for even these ages were too low (Tables 5 and 9). We derived estimates for low-recovery months by noting that the mean size during the winter is likely to lie between that of the previous summer and that of the following summer. In most cases we interpolated linearly between the month with the last good estimate for one age and the month with the first good estimate for the following age. In a few cases, variability in the month-to-month mean size estimates required some smoothing within the season to obtain a growth curve that was plausible. Appendix 3 details each modification we made in estimating the size distribution for each age, month, and category.

Given the estimated population mean and standard deviation, we then used the standard formula for the cumulative normal probability distribution to calculate the proportion of fish above any specified legal threshold.

Results

Figure 3 shows the mean length, standard deviation in length, proportion legal, and sample sizes for all months for all ocean CWT recoveries of ages 2 through 5. The apparent decline in size between August and September can be understood on the level of the population rather than of the individual fish. Maturing fish are, on average, larger than the fish of the same age that do not mature, and these individuals move to the river during this time. Fish that remain in the ocean tend to be smaller members of the population, so the mean size of the fish in the ocean declines. If this scenario is correct, then an analysis by KOHM area should show an increase in size within the KMZ during July and August (when fish from other areas move through the KMZ on their way to the Klamath River), while the mean size of the fish in other areas is still declining.

The mean length for age 3 is close to the legal limit shown (26 in), which means that the proportion legal is sensitive to small changes in the size distribution. Consequently, this age would be most strongly affected by any changes in the legal size limit.

Figure 4 shows the results with release types analyzed separately. Particularly striking is the decrease in differences among release types as they age. As might be expected, only age 3 types show strong differences in the proportion of fish that are of legal size, given a size limit of 26 in.

Figure 5 shows the results with fisheries analyzed separately. Sport recoveries do not show a decrease in size during August and September, which probably reflects the concentration of this fishery in the KMZ and the movement of larger fish into that area before they enter the river.

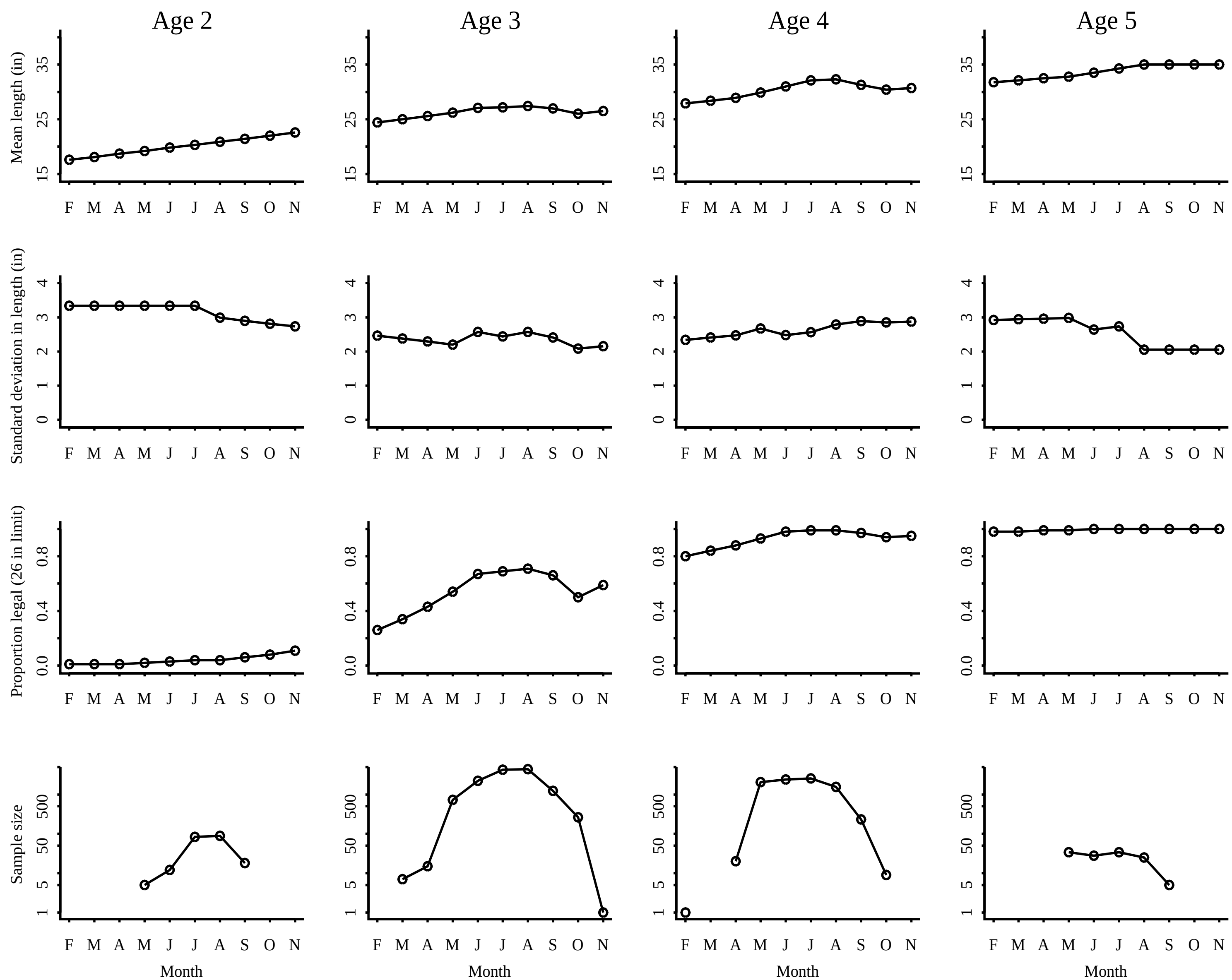

Figure 3. For all ocean CWT recoveries, estimated mean population length, standard deviation in length, proportion of legal size (given a minimum size limit of 26 inches), and sample sizes. Note that sample sizes are plotted on a logarithmic scale. The text describes the maximum likelihood and other methods employed.

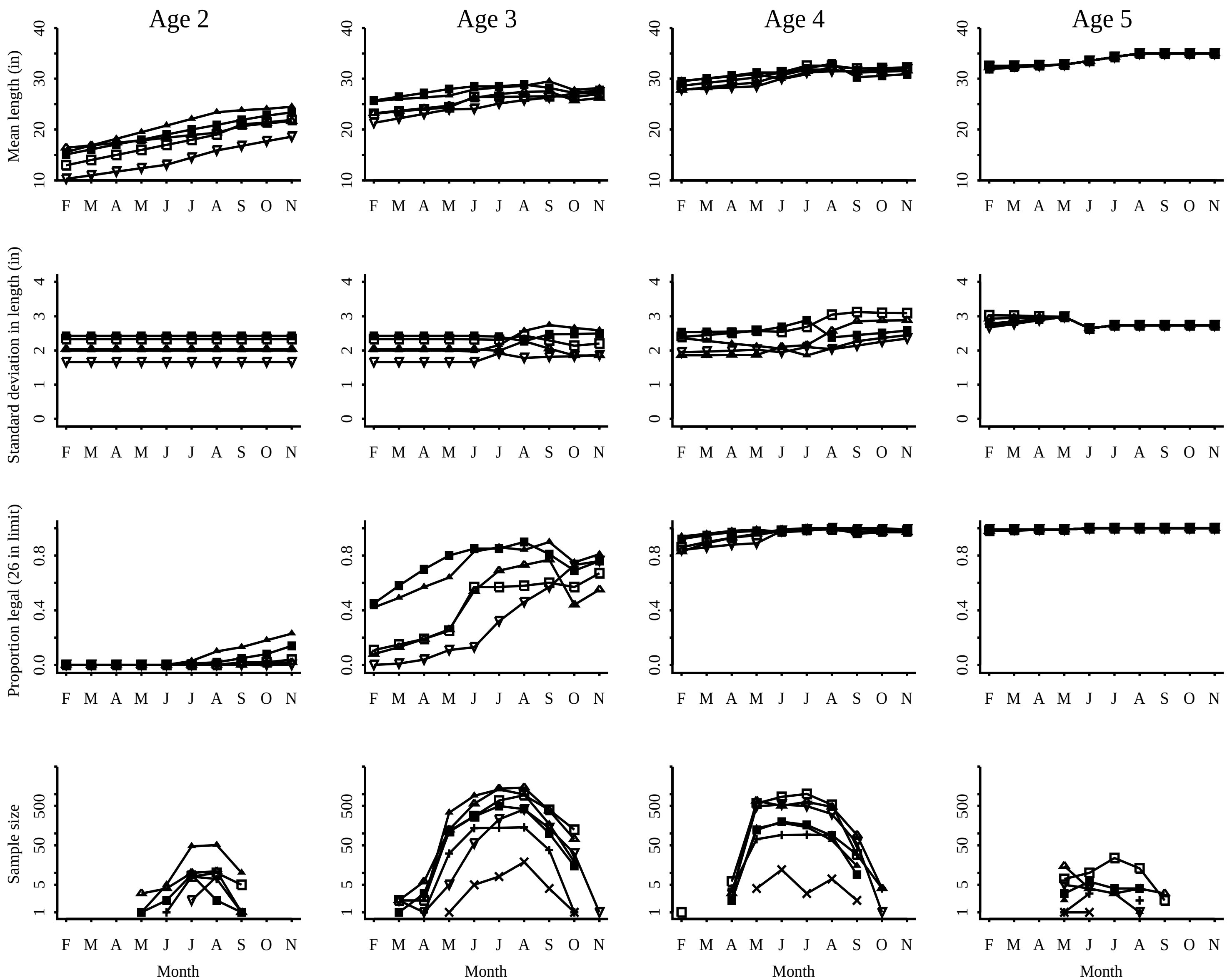

Figure 4. For all ocean CWT recoveries, with release types analyzed separately, estimated mean population length, standard deviation in length, proportion of legal size (given a minimum size limit of 26 in), and sample sizes. Sample sizes are plotted on a logarithmic scale. The text describes the maximum likelihood and other methods employed. Squares represent Iron Gate Hatchery releases, triangles Trinity River Hatchery releases, and crosses offsite releases. Solid symbols and "×" represent fingerlings; open symbols and "+" yearlings; inverted triangles represent yearling-plus releases.

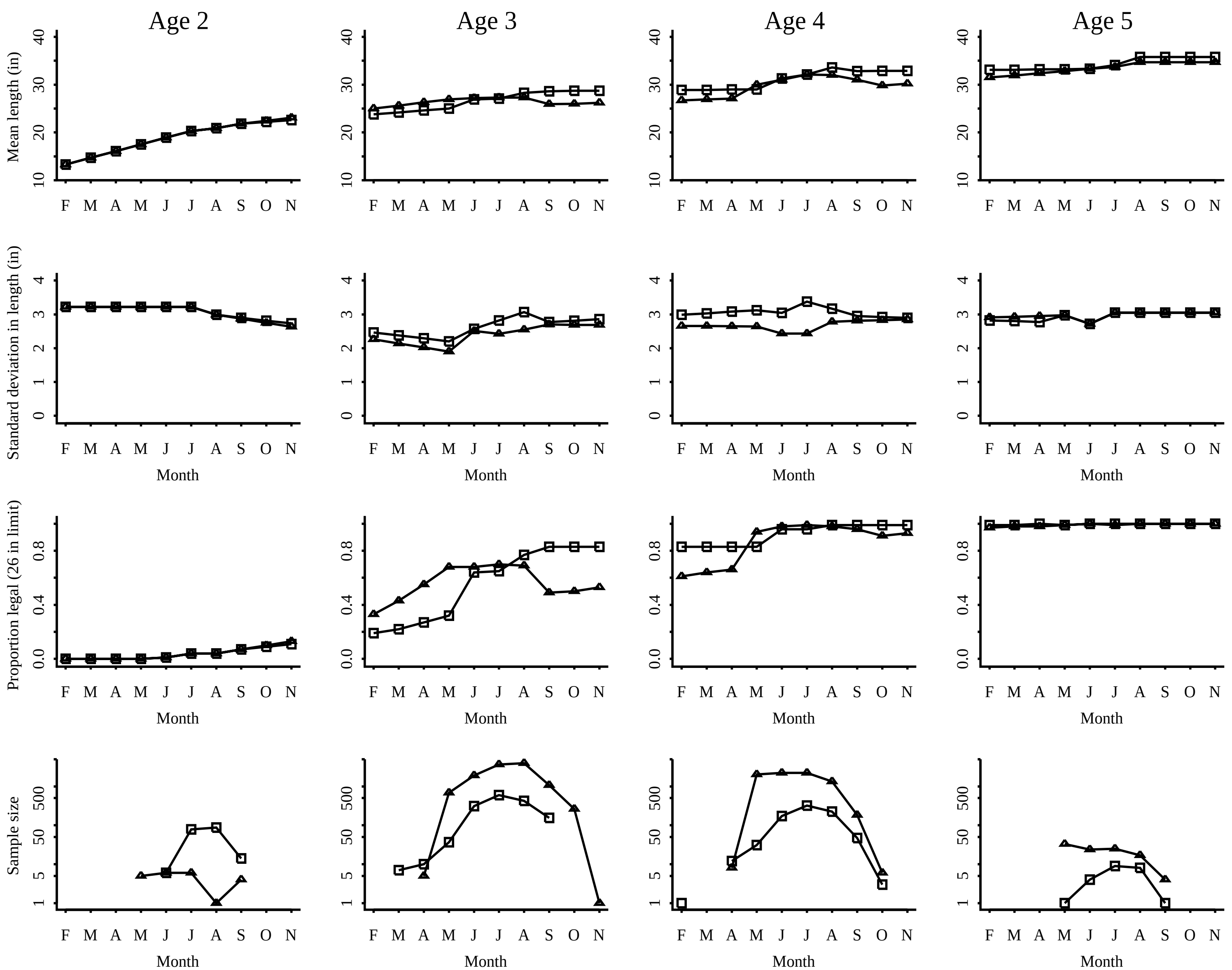

Figure 5. For all ocean CWT recoveries, with fisheries analyzed separately, estimated mean population length, standard deviation in length, proportion of legal size (given a minimum size limit of 26 inches), and sample sizes. Sample sizes are plotted on a logarithmic scale. The text describes the maximum likelihood and other methods employed. Triangles represent troll fisheries, squares sport fisheries.

Cohort analysis

Revision of the cohort analysis is central to the overall revision of the KOHM: a large number of inputs and outputs connect the cohort analysis to several databases, other analyses, and the KOHM itself (see Figure 1). Additionally, cohort reconstruction is in many ways the mirror image of the KOHM, performing backwards in time the same sequence of calculations that the KOHM uses to project a population into the future. The reconstruction sequence calculates many parameter values that are then used in the forward projection by the KOHM, and many of the improvements in this analysis carry over directly to the KOHM. The reconstruction uses catch-at-age methods similar to those of Pope (1972) and Hilborn and Walters (1992, p. 360).

The analysis involves of a series of Foxpro (Microsoft) databases that contain CWT data from brood year 1976 to the present and programs for manipulating these data. This structure makes it straightforward to check the correctness of many repeated calculations simultaneously, to modify the analysis in a consistent way, and to update the analysis as new data become available. Hard-coded values in the programs have been avoided where possible. The goal is to have a complete package of programs that read the release and recovery data from the Pacific States Marine Fisheries Commission (PSMFC) server and reconstruct the cohorts with minimal user intervention.

The age composition analysis gave estimates of the age composition of the entire in-river run, which contains both hatchery and natural components (the latter is taken to consist of fish that were born outside of hatcheries). The cohort analysis uses CWT recoveries (expanded for sampling and production) to estimate the age composition of each hatchery component of the run. Subtracting the hatchery components from the age composition estimates of the totals gives the age composition of the natural component of the run, which allows reconstruction of the natural part of each cohort, as described below. The estimate of the natural component also permits estimation of the proportion of the run that is composed of naturally produced fish, although this proportion is currently calculated from the Megatable (CDFG 2000).

Elements of the analysis

The cohort analysis includes fish of ages 2 through 6. Each cohort (brood year) is treated separately, and all months are included in the analysis. For hatchery fish, each release type is treated separately (the release code-specific production factors having already been applied), and natural fish are also treated separately. We generally follow Prager and Mohr (in press) in denoting rates with lower case letters and counts with upper case letters; ocean quantities with subscripted “O” and river quantities with “R” (we usually take the Klamath Basin to include the

Trinity Basin as well); and, among other variables, in our choice of C, H, and I to indicate contacts, harvest, and impacts respectively. Particular months are specified with an additional subscript.

The fundamental variables of the analysis are:

1. The number of fish in the ocean at the beginning of each month (N_O);

2. The number of fish contacted by fisheries in the ocean during the month (C_O);

3. The number of fish killed in the ocean during the month by harvest, hook-and-release mortality, and dropoff mortality (I_O);

4. The number of fish that mature and leave the ocean, whether to the Klamath or as strays to other river basins (M);

5. The number of mature fish that enter the Klamath River Basin (N_R);

6. The number of fish contacted in the Klamath River Basin (C_R);

7. The number of fish killed in the river by harvest or dropoff mortality (I_R);

8. The number of fish that survive to spawn (E);

9. The number of fish that spawn in natural areas (E_n).

For modeling purposes, fish are treated as maturing and entering the river at the end of August.

The parameters may be divided into those that are determined externally and those that are estimated by the cohort analysis and passed subsequently to the KOHM. The parameters that are determined externally include:

1. Ocean hook-and-release ("shaker") mortality rates (s_O), which are fishery-, time-, and area-specific. The rates used are the current rates adopted by the PFMC (STT 2000). Sport fishery recoveries in the SOC during the 1990s are further refined by major port area and month based on the relative proportion of anglers mooching and trolling;

2. The ocean dropoff mortality rate (d_O), which, according to policy that has been adopted by the PFMC (STT 2000), is 5% and is applied to the estimated contacts;

3. The ocean natural mortality rate (v_O), which is now incorporated monthly rather than applied once a year during the winter. For age 2 fish the monthly mortality is 0.0561257 (corresponding to 50% annually), and for older fish it is 0.0184235

(corresponding to 20% annually). The annual rates are from KRTT (1986).

4. The river dropoff mortality rate (d_R),which is 2% for the river sport fisheries and is 8% for net and seine fisheries, and is applied to the estimated harvest.

Quantities 1 and 3 have been revised; 2 is newly incorporated in the analysis. River hook-and-release mortality rates are not used because all hooked fish are assumed to be harvested. This assumption is not entirely correct: there are, for instance, occasional jack-only fisheries, as well as a complex set of bag and size limits (e.g., no more than one chinook salmon >22" in total length per day, out of a 2 salmon/day bag limit, and no more than 4 in any 7 consecutive days; no more than 8 chinook may be possessed, of which no more than four may be >22" in total length). The analysis would thus be more accurate with hook and release mortality included, especially because hooking mortality studies (both freshwater and ocean) have found some evidence that a higher hooking mortality rate may apply to larger fish (STT 2000).

On-line predation by sea lions is conceptually included in ocean dropoff mortality, but no attempt has been made to incorporate recent work that estimates the actual rate of loss.

The parameters that are estimated by the cohort analysis include:

1. Ocean contact rates (c_O), which are calculated as C_O / N_O, where C_O is the number of contacts in the month. Both C_O and N_O are specific to year, release type, age, and month. The numerator, and consequently the contact rate, is also KOHM area- and fishery-specific;

2. Ocean harvest rates (h_O), which are calculated as H_O / N_O, where H_O is the number of fish harvested during the month. Both H_O and N_O are specific to year, release type, age, and month. The numerator, and consequently the harvest rate, is also KOHM area- and fishery-specific;

3. Ocean impact rates (i_O), which are calculated as $(H_O + S_O + D_O) / N_O$, where S_O is hook-and-release mortality and D_O is dropoff mortality. The quantities are specific to the year, release type, age, and month. The numerator, and consequently the impact rate, is also KOHM area- and fishery-specific;

4. Maturation rate (m), which is calculated as $M \ / (M + N_{O,Sep})$, and is year-, release type-, and age-specific;

5. The straying rate (q), which is calculated as Q / M, where Q is the number of fish that mature and enter rivers other than those in the Klamath Basin; it is year-, release type-, and age-specific;

6. Klamath Basin harvest rates (h_R), which are calculated as H_R / N_R, where H_R and N_R are

specific to the year, release type, and age. The numerator, and consequently the harvest rate, is also fishery-specific.

Numbers 2 and 5 are newly incorporated in the analysis; the others have been revised. The cohort analysis also provides estimates of oceanwide abundances (by release group, age, and month), which are then used in the regression upon which the KRTAT stock projection is based.

A few fish have expansions for the proportion legal above 10x, in some cases exceeding 100x or even 1000x, because they were of legal size, yet were caught at a time that very few fish of their age class were of that length. The large expansions implied by such fish would have inflated the calculated impact rates correspondingly. We considered expansions above 10x (proportion legal < 0.10) as warnings of these unusual situations, and they flagged cases that indeed appear to contain data errors. In all such cases, the fish were listed as being of age 2, but their lengths ranged from 26.90 to 32.80 inches. Such lengths would be unlikely for an age 2 fish, and probably indicate a misreading of the coded-wire tag. Out of the entire ocean CWT database, seventeen fish, caught between 1981 and 1990, were in this class, and we excluded them from the analysis.

Figure 6 shows the scheme that underlies the cohort analysis and the KOHM. This diagram shows that the model is not formulated in a competing risks framework, although fish are confronted simultaneously by, for instance, the possibilities of being eaten and being harvested. Instead, this model presents the risks sequentially, with fisheries first, followed by natural mortality, and then, in August, the possibility of maturation. Because the monthly time steps are relatively short and the monthly rates low, the actual difference between the results of this formulation and those from a competing risks one are likely to be minor.

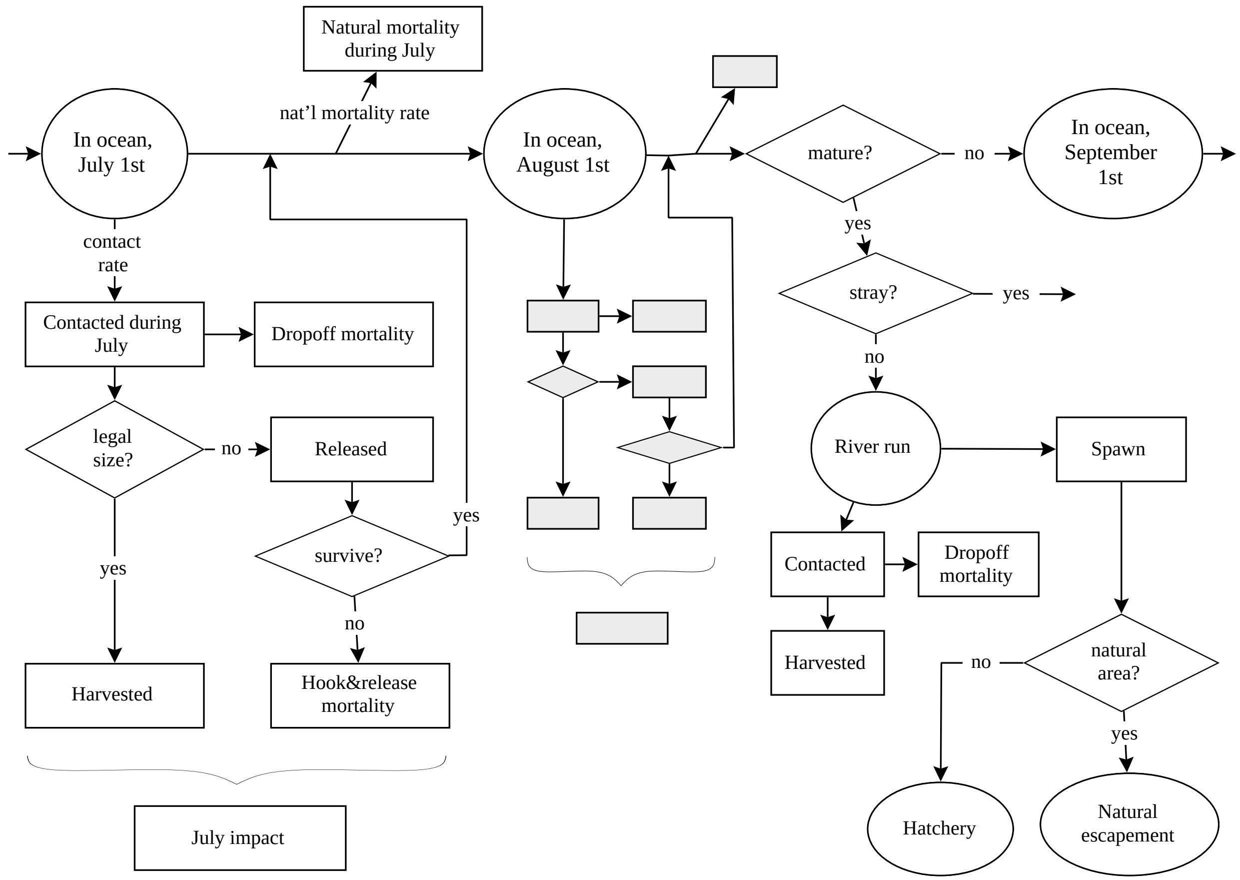

Figure 6. The sequence of events that underlies the cohort analysis and the KOHM; two monthly time-steps are shown. Along the top are the ocean populations and the natural mortality that subtracts from them. The region to the left involves fish that are contacted by ocean fisheries, and indicates the age- and fishery-specific factors that determine whether they survive the contact. As calculated, dropoff mortality does not come from a subset of the contacts, but represents additional mortalities that are calculated as a proportion of contacts. The smaller boxes in the center indicate the same ocean fishery processes during the subsequent month. To the right are the August-specific factors that involve maturation of fish and their return to the Klamath River at the end of August. The KOHM treats the river phase in more detail than does the cohort analysis. Any in-river size-limited fishery would add complications similar to those on the left side to the contact/harvest/dropoff area on the right.

The calculation sequence for hatchery fish

The cohort reconstruction proceeds backwards through time, from the last appearance of any members of a cohort (usually at age 5) to their initial appearance in the ocean fisheries at age 2. To the estimated abundance of fish in the ocean at a given time, each monthly step backwards adds estimated numbers of (1) fish lost to ocean fishery impacts; (2) ocean fish lost to natural mortality; and (3) between September and August, fish that mature and enter the rivers.

The following calculations are specific to a release type of hatchery fish, as well as to a given month, year, and age; some quantities are also specific to port. The oceanwide abundance at the beginning of month *t* is estimated as follows:

$$N_{O,t} = I_{O,t} + \frac{M + N_{O,t+1}}{1 - v_O}, \tag{5}$$

where $M = N_R + Q$ is nonzero only for t = August. The impacts of ocean fisheries include all sources of gear-related mortality, including harvest, shaker mortality, and dropoff mortality. Harvest and shaker mortality in turn involve contacts. Of the ocean contacts, all legal-sized fish die as harvest. Most fish smaller than the minimum legal size limit are released, but a proportion of the released fish also die because of hooking injuries. This hook-and-release mortality depends on the fishing method and gear used (STT 2000). Other fish, regardless of size, encounter the gear and escape before being landed, but die because of wounds received or because of quick-acting predators; in many cases their escape or death by predation occurs before the contact is detected by fishermen. This dropoff mortality is currently calculated as 5% of total contacts (STT 2000). These fish are not part of the total contacts as represented in the formulas, although some kind of contact is clearly involved; this use of words leaves room for confusion, but the problem is terminological rather than conceptual. Ocean impacts are then estimated by adding these three sources of mortality:

$$\begin{aligned} I_O &= H_O + S_O + D_O \\ &= H_O + s_O \cdot (C_O - H_O) + d_O \cdot C_O. \end{aligned} \tag{6}$$

The ocean contacts are calculated by expanding the legal-sized portion of the ocean harvest, $H_{O,legal}$, by the proportion legal, p_{legal}, for that release type-, month-, and fishery-specific minimum size limit in effect:

$$C_O = \frac{H_{O,legal}}{p_{legal}}. \tag{7}$$

The difference between contacts and harvest, $(C_O - H_O)$, equals the difference between the sublegal portions of the contacts and harvest, $(C_{O,sublegal} - H_{O,sublegal})$, because every legal-sized fish is assumed to have been retained. This difference then represents the hook-and-release mortality on sublegal fish that were released; the 100% impact rate on harvested sublegals is already included in H_O. This difference is taken to be zero in the few cases for which it would otherwise be negative.

In a few cases (103 out of 2823 when analyzed by month, major port, fishery, age, brood year, and release group), the number of actual sublegal recoveries exceeded the estimate of sublegal contacts as calculated with the above expansion. These cases were probably due to sampling effects, and usually involved only small numbers of fish in the older age classes, for which only a very small fraction of the estimated size distribution was below the legal limit. We resolved the discrepancies by adding the excess sublegal recoveries to the estimates of the sublegal contacts and total contacts.

To estimate ocean harvest of hatchery fish, each Klamath fall run chinook CWT recovery is expanded for sampling, production, and CWTs that were not decoded successfully (successful decoding requires that two independent readers note the same code, and that it appear in the listing of codes issued by the tag code coordinator of each state):

$$H_O = \sum_{\substack{\text{Klamath} \\ \text{fall chinook} \\ \text{CWT recoveries}}} \left(\frac{1}{p_{sampled} \cdot p_{tagged} \cdot p_{processed} \cdot p_{decoded}} \right), \tag{8}$$

where $p_{sampled} = n_{sampled} / \hat{L}$ is the proportion of the catch sampled at the dock, and p_{tagged} is the proportion of the hatchery release that is tagged. The quantity p_{tagged} is supplied by the hatcheries, and is specific to each release group; fish that shed tags usually do so before they are released from the hatchery, so the expansion for hatchery production already includes these cases. The factors $p_{processed}$ and $p_{decoded}$ account for losses of CWTs between sampling at the dock and successful reading of the code, as described below.

The adjustment for problematic CWTs includes cases in which the head was taken in the sample but not processed; heads in which the tag was not found (presumably because the fish shed the tag; these fish are still identified by the adipose fin clip); and those in which the extracted tag was not successfully decoded (because the tag was lost during processing, because it was unreadable, or because there were unresolved discrepancies among its readings). The following quantities demarcate the relevant steps:

$$\begin{aligned} n_{heads} &= \text{number of heads taken in sample;} \\ n_{processed} &= \text{number of heads processed;} \\ n_{extracted} &= \text{number of CWTs extracted;} \\ n_{decoded} &= \text{number of CWTs that were successfully decoded.} \end{aligned} \tag{9}$$

The factor $p_{processed}$ accounts for fish that were taken at the dock but not processed:

$$p_{processed} = \frac{n_{processed}}{n_{heads}} . \tag{10}$$

Fish that were not processed included some fish that would have been found to lack CWTs had they been processed. Among the heads that were processed, the tags that were extracted but not read successfully are taken into account with $p_{decoded}$, the proportion of extracted CWTs that were successfully decoded:

$$p_{decoded} = \frac{n_{decoded}}{n_{extracted}} . \tag{11}$$

Assignments to release groups cannot be made for problematic CWTs, so these factors lump release groups while remaining specific to a port, month, and year. Equation 8 then shows how these four factors combine in the calculation of the ocean harvest of hatchery fish, and Equation 6 shows how the harvest is incorporated in the calculation of total fishery impact.

Figure 7 shows how the cohort analysis brings together the quantities N_O, N_R, M, and I_O in reconstructing a single month in the history of a cohort.

The cohorts released within the most recent four years are incomplete in the sense that they have not finished their five-year life span. These cohorts can still be included in the cohort analysis by a slight modification of the above scheme. For the hatchery and natural fish, the September "Given" quantity, instead of being derived beforehand, can be estimated from the inriver run and the average age-specific maturation rate as estimated from the previous cohorts. The formula is

$$N_{O,Sep} = M \cdot \frac{1 - m}{m} . \tag{12}$$

The estimate when only one year is missing is relatively robust, because the age 5 abundance of a cohort is small relative to its age 3 and age 4 abundances; the estimate when two years are missing is less robust. Including these incomplete cohorts in the analysis adds another brood year to the ocean abundance predictor regressions in the KRTAT stock projection (KRTAT 2000).

In one particular case, at the last appearance of the members of a cohort (that is, at the beginning of its reconstruction), the estimated number of contacts exceeded the estimated ocean abundance. This discrepancy was a problem because the analysis assumes that fish are contacted no more than once in a given month. No members of the cohort were detected subsequently to add to the ocean abundance at the beginning of the month in question, nor were there any river recoveries, so we were faced with the impossibility of the number of contacts exceeding the ocean abundance. These discrepancies were due to sampling effects with a small cohort: there were only two recoveries from it at age 3 and none subsequently. We resolved the problem by starting the reconstruction with the estimated number of contacts rather than the estimated number of impacts, and inferring that the remaining members of the cohort were present in later months but had escaped detection.

Klamath Basin inland CWT recoveries from the river run were compiled from sport, net, spawning ground, weir, and hatchery sampling data. No minimum size limit was assumed for the sport fishery, so total contacts were taken to equal harvest. To convert contact to impacts in the river sport fisheries, CWTs expanded for sampling were also multiplied by 1.02 to account for 2% dropoff mortality. Similarly, sample-expanded tag recoveries from net and seine fisheries were multiplied by 1.08 to account for an 8% net dropoff mortality. Spawning ground surveys, hatcheries and weir recoveries did not require additional mortality expansions.

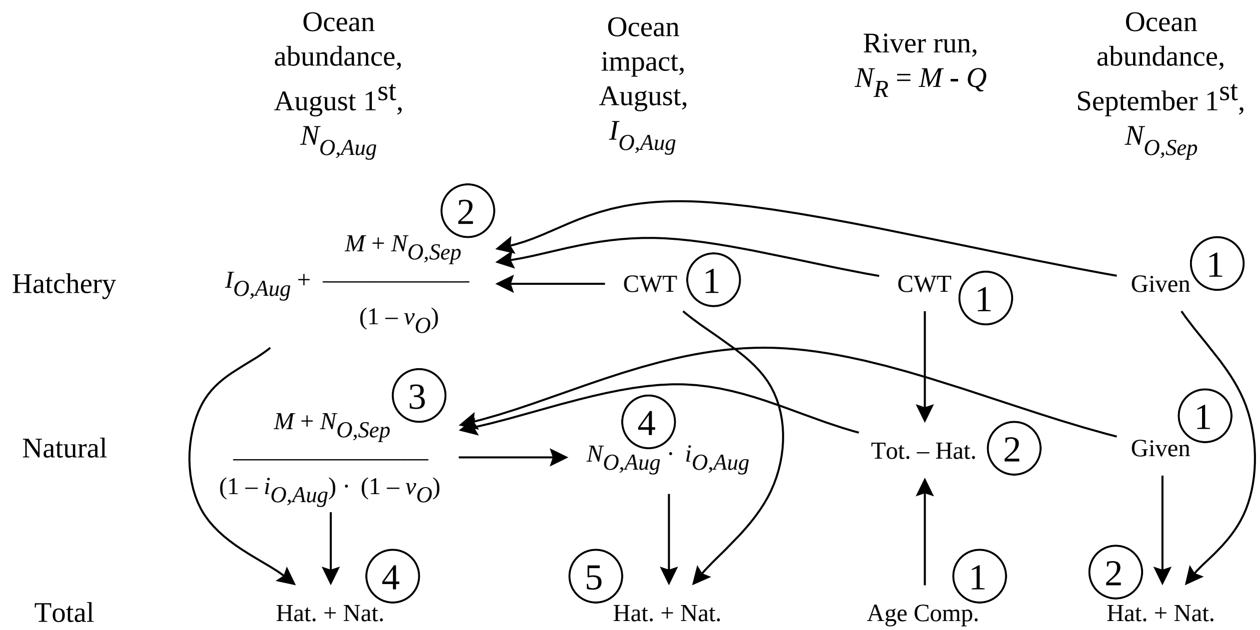

Figure 7. The sequence of calculations for one month of the cohort reconstruction. Time advances left to right. The calculations iterate backwards in the order indicated by the numbers in circles; quantities with higher numbers are calculated after those with lower numbers. The span from August 1^{st} to September 1^{st} is shown; other months are simpler because of the absence of the river run ($N_R = M = 0$). Fishery impacts occur between the columns for $N_{O,Aug}$ and $I_{O,Aug}$; natural mortality, maturation, and straying occur between the columns for $I_{O,Aug}$ and N_R. For the last appearance of a cohort, the "Given" value at the beginning of the following month is taken to be zero; for all other months the value is the result from the previous step. Expansions for sampling and production are implicit. In the actual analysis, each hatchery release type of the cohort has its own row, and its calculations are performed separately. CWT = the number of fish based on coded-wire tag recoveries; Age Comp. = the number of fish entering the Klamath River as estimated by the age composition analysis; v_O = natural mortality rate; $i_{O,Aug}$ = the fishery impact rate calculated from the hatchery fish and applied to the naturals; the calculations for the natural fish are described more fully in the text. The quantities in the formulas are specific to the row and column on which they appear.

The calculations for natural and total fish

Calculations for natural and total fish are complicated by possible differences between the hatchery and natural components: ocean impacts and straying of the natural component are not known, and must be extrapolated from the impact and straying rates estimated for the hatchery component. This extrapolation has not yet been done. Ocean impact rates are likely to differ for fish from the Klamath Basin and those from the Trinity Basin, and the proportion of natural fish from each basin is unknown. If the differences between ocean impact rates are small for fish from the two basins, then a simple mean impact rate may suffice for natural fish, but if these differences are large, then a more complicated weighting may be necessary. The weighting used in the previous cohort analysis was probably inaccurate. The need to calculate the impact and straying rates on hatchery fish before the cohort reconstruction can be carried out for natural fish is an illustration of the iterative nature of this analysis.

Figure 7 shows how, given an estimate of the impact and straying rates of hatchery fish, estimates of the size of the hatchery component of the inriver run, and the estimate of the total inriver run (which comes from the age composition analysis), it is possible to derive estimates of the abundance of the natural component of the ocean population and the fishery impact on that component. In particular,

$$N_{O,t} = \frac{M + N_{O,t+1}}{(1 - i_{O,t}) \cdot (1 - v_O)} \tag{13}$$

and

$$I_{O,t} = N_{O,t} \cdot i_{O,t}\,, \tag{14}$$

where $i_{O,t}$ is the impact rate estimated from hatchery fish and applied to the natural fish, and M is calculated as follows. For hatchery fish, $N_R = M - Q$, which can be rewritten $N_R = M \cdot (1 - q)$, and which gives the estimate of the straying rate $q = 1 - (N_R / M)$. This straying rate is then used to calculate the number of maturing natural fish, $M = N_R / (1 - q)$, which is then added to the ocean abundance at the beginning of September in the calculation of ocean abundance at the beginning of August. Once the estimates for the natural component are known, the totals for all components of the cohort can be calculated by summation.

Other fisheries

Although we have focused on the ocean sport, ocean non-treaty troll, Klamath Basin inriver sport, and Klamath Basin inriver treaty fisheries, the database ALLKOHMREC.dbf includes recoveries in several additional fisheries (Table 11), and we have incorporated these data in the cohort analysis.

One of the difficulties in interpreting these numbers is that the sampling expansion is not complete. For instance, the groundfish sampling expansion is only within sampled boats, and there is no expansion to unsampled boats; consequently, the expanded numbers may represent as little as 1% of the actual take (T. Turk, NWFSC, pers. comm.). This underestimate is so substantial that inclusion of these fisheries with these current numbers may be misleading by suggesting that their impacts have been dealt with adequately. However, with the possibility of better sampling programs in the near future, we have included these fisheries in the analysis to facilitate incorporation of better data when they become available. The ocean treaty troll fishery was analyzed in the same way as the commercial ocean troll fishery. For the freshwater fisheries the shortcomings of the sampling and expansions are similar, although the possibility of better sampling programs in the future is not as likely. However, the freshwater recoveries represent fish that matured and then strayed outside the Klamath Basin, so these recoveries constitute our source of data for the straying rate. Because of the incompleteness of these data, the estimates we derive represent only lower bounds for the actual straying rates.

Take of Klamath chinook salmon in many of these fisheries represents “bycatch,” so it was not expanded for the proportion legal in our analysis.

For the cohort reconstruction, all ocean fisheries were treated together, as contributing to the total impact in a given month. Afterwards, the calculation of contact rates is separate for each fishery; in this way, fisheries that have been discontinued can be incorporated in the historical part of the analysis, but not in the projections of the KOHM.

To assess the importance of errors introduced by incomplete accounting for other fisheries, we performed a series of comparisons between hypothetical populations and cohort analyses that were derived from them but based on incomplete data. We created a set of scenarios with several run sizes and ocean harvest levels and typical values for other parameters. For each scenario, we performed a simple cohort reconstruction, and used the results of the reconstruction to project forward with KOHM-like calculations. We then introduced into the reconstructions “errors” in the given straying and harvest levels, and compared the results to the projections without those errors. Table 12 shows the results of the comparisons; when ranges are given the exact values are specific to the particular parameter values chosen for these comparisons (the straying rate used was 3.85%; the ocean harvests ranged from 12% to 24.5%). Neglecting straying altogether resulted in greater than 3% errors in projected harvest and impact rates, but no errors in the projected harvest, impacts, run size, or ocean abundance. Errors in the estimate of ocean harvest carried through to errors of exactly the same size in the projection of ocean harvest (as might be expected) and impacts, and somewhat smaller errors in harvest and impact rates.

Table 11. Other fisheries for which the databases include recoveries of Klamath chinook salmon, and the number of recoveries in each fishery.

Fishery	Recoveries	Expanded for sampling	Expanded for sampling and production
ocean total	422	977.71	6166.76
ocean troll, treaty	16	42.17	322.71
groundfish observer	404	933.54	5837.43
ocean trawl bycatch	2	2	6.62
freshwater total	719	986.82	4916.07
Columbia R. gillnet	68	278.18	1166.81
coastal gillnet	5	13.68	17.95
freshwater net	1	1.41	1.99
freshwater seine	46	43.22	388.3
estuary sport	7	33.31	123.8
freshwater sport	5	3.5	34.55
hatchery	554	572.89	2877.82
fish trap	29	34.42	269.91
spawning ground	2	4.21	25.18
test fishery net	1	1	4.88

Table 12. The propagation of errors in the estimates of straying or harvest to subsequent errors in the projections of six quantities. The entries are the error in the projected quantity given either 100% error in the estimated straying rate (neglecting straying altogether) or 5% error in the estimated ocean harvest. Ranges are over the different scenarios (see text).

	Error in projection of:					
Type of original error:	ocean harvest	ocean harvest rate	ocean impacts	ocean impact rate	river run	ocean abundance
Straying (100%)	0%	0.8 - 3.1%	0%	0.8 - 3.1%	0%	0%
Ocean harvest (5%)	5%	3.6 - 4.3%	5%	3.6 - 4.3%	0%	0%

It is worth noting that the propagation of error is not specific to uncertainty in data collected from other fisheries, but applies to errors in the input quantities that arise for any reason. Also, the errors in these comparisons were applied independently; actual combinations of errors probably interact in more complicated ways, and may affect other quantities projected by the KOHM as well. Nonetheless, these calculations may give some general idea of the sensitivity of the results to the quality or completeness of the input data.

Additional considerations

Barbless hooks were required coastwide in 1984 (PFMC 2000), and it might be appropriate to increase hooking mortality rates by 5% for both commercial and sport fisheries before then. The different rates are not now incorporated, but might be incorporated in the future. Similarly, changes in mooching styles outside of California have yet to be investigated.

The southern California cell is currently treated as a single unit, although effort and contact rates probably differ markedly among the subunits identified in Table 2. Further work may split this cell into two or more cells, so that the rates can be estimated for each area separately. Having rates that are more specific to each area would be desirable from a management point of view. One limiting factor in such a decision is the potential for imprecise estimates due to low sample sizes in the smaller cells; the smaller the subdivisions, the larger this possibility.

Discussion

The databases and analyses described here provide the biological foundation of the KOHM: they supply, among other quantities, the age structure and size structure of the population through time, and an accounting of each cohort since brood year 1976, including the impacts of ocean and river fisheries. Although these analyses estimated contact, harvest, and impact rates, they examined neither the relationship between contacts and fishing effort, nor the dynamics of fishing effort in relation to management regulations or economic factors. The effort analysis and the contact-effort analysis will supply information about these further relationships. Also remaining is the all-stocks analysis, which will examine (although in much less detail) the concurrent effects of these fisheries on other salmon stocks generally. The reimplementation of the KOHM in a structured programming language will bring together these improvements and provide a simpler means of incorporating new data as they become available, and of modifying the model itself in the future. This ease of upgrading has already been accomplished for the databases and their accompanying programs.

By themselves, the present analyses demonstrate high levels of variability of several kinds. Fluctuations in the age composition of the river run reflect variability in abundance, maturation rates, and ocean survival. Differences in size distributions among different groups of fish reflect differences in origin and in the river and ocean environments. Declines in harvests during the 1990s reflect changes in population levels, curtailed fishing seasons, and economic factors. This degree of variability increases the value of cohort-specific analyses and models, as well as incorporation of all data, rather than only that within a designated base period, in deriving estimates of the model's parameters.

Although the work that has been completed represents a significant improvement over previous efforts in terms of accuracy, biological realism, and completeness, it will not be used in the 2000 management season. The structure of the new analyses is different enough from the old that the new results cannot simply be dropped into the existing model without creating inconsistencies that would undermine the goal of greater rigor and accuracy. As the high degree of interconnectedness in Figure 1 suggests, consistency requires that virtually all of the work be completed before any of it can be used. This top-to-bottom consistency will be one of the strengths of the KOHM once it is complete.

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Appendix 1:The structure and construction of the databases

Ocean CWT databases

Release data

KOHM_REL.dbf has the following fields:

RELGROUP
BRDYR
CWTCODE
RUN
RUNAME
SPP
STK_LOC
FISHWT
RELDATE
RELSTAGE
REARTYPE
TYPEREL
TAGGED
SHEDTAG
UNTAGED
PRODFCT
COMBO
HATCHERY
RELEASITE
STOCKNAME
AGENCY
RELNOTES

Recovery data

RMIS_REC_STRU.dbf is the blank database template used to download all Klamath chinook recoveries from the PSMFC server (downloaded as CSV._____.txt files). During the running of the program, records are added to it, but it is deleted after the data have been put into the database ALLKOHMREC.dbf.

The database RMIS_REC_STRU.dbf has the following fields:

AGENCY: reporting agency
HEADTAG: recovery ID
CDATE: recovery date
PERIODTYPE: sampling period type
PERIOD: sampling period number
SPP: species
LENGTH: length value
LENCODE: length code
CWTCODE: tag code
SAMPSITE: sampling site
AREACODE: recovery site code
FISHERY: fishery code
ESTNUM: sampling expansion
SAMTYPE: sample type
RUN
SAMAGENCY: sampling agency
RUNYR: run year

The program GETALLRECOVERIES.prg appends the CSV text files into the blank RMIS_REC_STRU.dbf, and then transfers the appropriate data into ALLKOHMREC.dbf. This database is then linked to the release file KOHM_REL2000 to obtain all pertinent release information. It is also linked to several other databases to obtain actual catch areas and fishery names.

Additional information:

Release group
Brood year
Age
Fishery name
Catch area
Total length
Month recovered
Production factor
Run name
Stock name

This program copies all ocean recoveries into ALLOCEANREC.dbf in proper format, and copies all other river basin recoveries into OTHERRIVERREC.dbf in proper format for use in the cohort reconstruction

The program GETKOHMAREA.prg performs three separate functions on ALLOCEANREC.dbf:

1. adds KOHM area based on sampling site (uses SITEAREA.dbf; see below);

2. runs NEWEXP.prg, which gets new expansion factor for CDFG samples. The formula previously used was updated in 2000 and applied to CDFG master catch-sample database (KOHM_CS); and

3. checks to make sure that the KOHM area was open on the stated sample date, using a regulations database (OCEANREGS.dbf; see below). If the area was not open, the program links to FIXEDKOHM.dbf to obtain the correct KOHM area. The file FIXEDKOHM.dbf contains approximately 440 recoveries in areas that were officially closed; these recoveries were corrected line by line and put into a file so that they do not need to be re-corrected in future downloads.

Additional information:

KOHM area
Major port

The database SITEAREA.dbf (86 records) associates sampling sites with KOHM areas; it contains the following fields:

AGENCY
SAMPSITE
MJPORT
KOHMAREA
AREACODE
CATCHAREA

The program GETLIMIT.prg uses the regulations database (OCEANREGS.dbf) to obtain the minimum size limit in effect for all ocean recoveries based on the fishery, the sample date, and the KOHM area of each. This minimum size limit is used in the cohort reconstruction in determining the percentage legal for a given recovery.

Additional information:

Minimum size limit

The program CREATE_RECFILE.prg automatically runs GETALLRECOVERIES.prg, GETKOHMAREA.prg, and GETLIMITS.prg. It appends needed data into OCEANCWT.dbf in the format needed for the cohort reconstruction.

The database ALLOCEANREC.dbf (23,482 records) contains all ocean CWT recoveries. Each record has the following fields:

* RELGROUP
AGENCY

HEADTAG
CDATE
* DATEREC
* RUNYR
* BRDYR
* MONTHREC
PERIOD
* LENGTH
* TL_IN
* MINSIZE
* CWTCODE
* SAMPSITE
* KOHMAREA
* MJPORT
* AGE
* FISHERY
ESTNUM
* NUMTAGS
* PRODFCT
SPP
RUNAME
STOCK
AREACODE
FISHRYNAME
CATCHAREA

The database OCEANCWT.dbf (23,485 records) is a subset of ALLOCEANREC.dbf that contains all records but only the sixteen fields marked above with *. The cohort reconstruction programs uses this database to determine ocean contacts, impacts, abundance, and so forth.

The database OTHERRIVERREC.dbf (726 records) has information about fish recovered in river basins other than the Klamath/Trinity Basin. It has the following fields:

HEADTAG
DATEREC
RELGROUP
CWTCODE
FISHERY
RUNYR
BRDYR
AGE
MJPORT
NUMTAGS

PRODFCT
AGENCY
SAMPSITE
SPP

The database FISHERYCODES.dbf (23 records) has the following fields:

AGENCY
FISHERY
FISHRYNAME

The database CATCHAREAS.dbf (125 records) has the following fields:

AREACODE
CATCHAREA
AGENCY

Regulations database

The database OCEANREGS.dbf (795 records) contains fishery regulations for non-treaty ocean sport and commercial fisheries from 1978 to the present, as referenced by the PFMC (2000). It also contains regulations for other ocean recoveries found in ALLOCEANREC (e.g., treaty commercial, groundfish trawl, Canadian fisheries). It has the following fields:

AGENCY
KOHMAREA
FISHERY
SYEAR
SDATE: starting date
EDATE: ending date
BLIMIT: bag limit
SLIMIT: size limit
AREACODE
TES
STATE

Catch and effort databases

The database CATCH_EFFORT.dbf (approximately 1,700 records) has the following fields:

RUNYR

MONTHREC
MJPORT
AREA
FISHERY
CHIN_CATCH
DAYSFISHED
CPUE

The database COMM_EFFORT.dbf (361 records) is used directly to compare California catch/sample totals in PFMC (2000) directly to the catch/sample values in the analysis.

RUNYR
MONTHREC
MJPORT
AREA
FISHERY
CHIN_CATCH
NEWCATCH
ORIG_SAMP
CHIN_SAMP
DAYS_SAMP
DAYSFISHED
NEWDAYS
CPUE
NEWCPUE

Inland CWT database

The database KOHM_INLAND.dbf contains 2447 records. Each record has the following fields:

CWTCODE
AGENCY
RUNYR
BRDYR
RELGROUP
SAMPSITE
KOHMAREA
AGE
FISHERY
ESTNUM
SPECIES

RUN
STOCKNAME

All of the above field names comply with the RMIS CWT Data file naming definitions (version 3.2) except for the following:

<u>KOHMarea</u>

NET = Tribal net
SPOR = River sport
HAT = Hatchery
NAT = Natural spawning ground escapement

<u>Agency</u>

HVT = Hoopa Valley Tribe
YT = Yurok Tribe
FWS = US Fish and Wildlife Service
CDFG = California Department of Fish and Game

<u>Sampsite</u>

KRIV = Klamath River
TRIV = Trinity River

<u>Relgroup</u>

IGHF = Iron Gate Hatchery fingerlings
IHGY = Iron Gate Hatchery yearlings
IGHZ = Iron Gate Hatchery yearlings plus
TRHF = Trinity River Hatchery fingerlings
TRHY = Trinity River Hatchery yearlings
TRHZ = Trinity River Hatchery yearlings plus
XHAF = Extra Hatchery Production fingerlings
XHAY = Extra Hatchery Hatchery yearlings
WilF = Wild fall run.

Appendix 2: Comparison of USFWS beach seining and previous COHORT spreadsheet methods of age composition analysis for the 1984-1990 period

For the 1984-1990 period, the previously used COHORT spreadsheet employed an unusual series of age composition calculations despite the availability of USFWS estimates based on beach seining and scale analysis. Instead, the spreadsheet extrapolates the age composition of CWT recoveries to natural fish by applying a complicated multiplicative factor. Explanations of the exclusion of the USFWS analyses from the years 1984-1990 cite concern that seining efforts may have oversampled the early portion of the run, thus biasing the estimate away from younger fish because the late portion of the run contains a higher proportion of Trinity basin fish, which tend to mature at younger ages than do Klamath basin fish. The COHORT spreadsheet did use the USFWS estimates for 1979-1983.

This Appendix examines the USFWS methodology for possible sources of bias, and compares the results of the two methods. No apparent source of bias in the USFWS methodology emerges, and the estimates of the two methods do not differ in any systematic way. The only notable difference between the two sets of estimates is in the opposite direction of that which would be expected if the COHORT technique were correcting a bias away from younger ages. It is not impossible that a bias exists, but it would be shared by both approaches, and the USFWS approach has the virtues of simplicity and consistency.

The USFWS beach seining methodology

As Table A1 shows, the sampling periods included virtually the entire span of the run in every year's sampling period. The figures in the USFWS reports show that the catch per effort values begin low, rise to the peak of the run, and decline to negligible levels before the end of sampling. At most, a very small proportion of the run was lost at the end of the sampling period, which represents too small a number of fish to affect the estimate of the overall age composition throughout the basin. Further, the sampling design involved a nearly constant level of effort over the duration of the sampling period, especially after 1985, when the number of sets per day and the proportion of fish sampled in each set were held constant throughout the season. Even in earlier years, sampling was done on a fixed number of days per week, and the sampling procedures were similar from day to day.

In some years, small sets (the collection of fish caught in the beach seine) were sampled completely while some large sets were only subsampled. The reports indicate that efforts were made to compensate statistically for these differences, but the actual statistical manipulations are not presented. If uncorrected, this subsampling would bias the estimates away from the peak of the season (when the largest runs occur) and toward the tails.

All sampling was during daylight hours only, with the period of sampling varied to include all tidal phases, although the details of the scheduling are not described in the reports. In 1990 the sampling was centered about the low slack tide, which is when most fish were found to transit. Although the timing of sampling may have introduced some variability in the sampling efficiency from day to day, it seems unlikely that these procedures introduced a systematic bias over the entire season.

Table A1. Sampling schedule for USFWS beach seining

Run year	Sampling start	Sampling end	Days per week
1980	24 June	28 September	4
1981	13 July	25 September	5
1982	19 July	22 September	5
1983	15 July	5 October	5
1984	17 July	28 September	5
1985	15 July	25 September	5
1986	16 July	30 September	5
1987	13 July	6 October	5
1988	18 July	22 September	4
1989	17 July	22 September	4
1990	23 July	2 October	4

It is conceivable that the net itself may have created a size-related bias, by allowing smaller (younger) fish to escape while catching larger fish more efficiently. The mesh size was 8.9cm (=3.5in) throughout the study. However, the concordance between the USFWS estimates and the previous COHORT estimates reduces the likelihood that such a bias in involved. The location of the sampling changed from year to year in response to the shifting of the spit. In all years the attempt was made to sample from the deep, cold part of the channel. It is possible that the passage of fish through the channel resulted in differences in vulnerability among size classes, but it is hard to evaluate this possibility in the absence of further data, and it is unlikely that it introduced any bias from one part of the season to another. In 1986, 20% of the sampling was from an alternate location. The only statistically significant difference found between the samples from the two sites was in the size of the jacks.

Comparison of the results of USFWS beach seining and previous COHORT spreadsheet methods

Graphs of the COHORT spreadsheet estimate vs. the USFWS beach seine estimate of the proportion of each age class present in each year's run show a low degree of scatter about the 45° line (Fig. A1). The stated bias in the beach seining data would cluster points primarily below the 45° line for ages 2 and 3 and above the line for ages 4 and 5 (ages 2 and 5 are less important than are ages 3 and 4, but are included in these comparisons for completeness). However, for every age, the distribution of the data seems consistent with the 45° line, which means that the two methods rarely differ substantially in their estimates. The few differences are discussed individually below; their small number shows that either the concerns about bias are not supported empirically or that the COHORT spreadsheet method shares the bias.

Run year 1989, age 3 and age 4

The primary ages of concern are 3 and 4, because they dominate the run numerically, and the only year for which these estimates differ substantially is 1989. The point for the 1989 estimates is the leftmost on the age 3 graph and the rightmost on the age 4 graph. These differences are in the opposite direction from that expected if the beach seining were biased as described.

Although it is impossible with the given information to determine which estimate is truly more accurate, it is possible to judge which one is more plausible, using as a criterion consistency with the estimates given by each method for the other years. The USFWS-estimated proportions lie within the observed range of values (0.3 standard deviations away from the mean for age 3, and 0.8 SDs from the mean for age 4), while both COHORT proportions lie outside the range of all other years (1.3 SDs from the mean for age 3, and 1.6 SDs from the mean for age 4).

The total run declined by 38% from 1988 to 1989, and by 70% from 1989 to 1990 (Table A2). This decline provides an independent means of evaluating the results of these two methods through the examination of "run ratios" for each brood year. The run ratio A3/A2, for instance, is the number of age three fish in the run divided by the number of age 2 fish in the previous year's run; it depends on the maturation rates for that cohort for both years and the ocean impact and mortality rates during the intervening year. The relevant run ratios here are A3/A2 and A4/A3 for the 1986 brood year, and A4/A3 and A5/A4 for the 1985 brood year. For each ratio, the FWS estimates give values for these years that are at or below the means for all years; for 1989-1990 both of the observed transition ratios (0.44 and 0.018) are below the ranges observed for all other years. In contrast, the COHORT estimates are scattered above as well as below the means, and the ratio that was above the mean, A4/A3 for brood year 1986 (1.75), corresponds to the greatest decline in the run (1989-1990). Further, the only ratio that is below the range of the other observations is that for the age 2 to age 3 transition for 1988-1989 (0.63), which is the year with the smaller overall decline in run size.

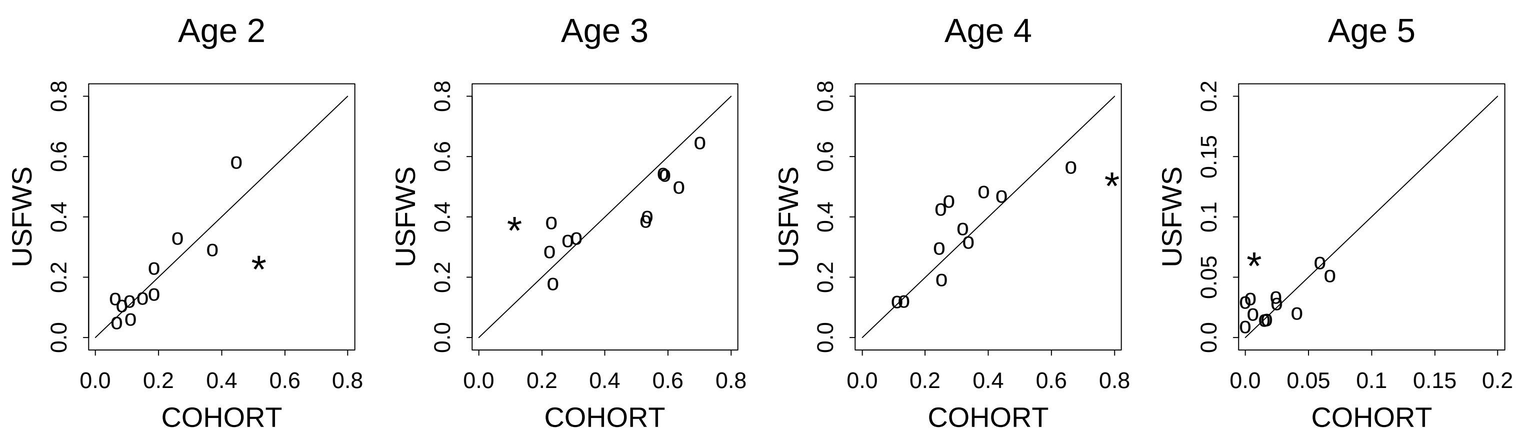

Figure A1. Comparisons of the estimates of the proportion of fish of each age, as estimated by the COHORT spreadsheet and USFWS beach seining methods. The 45° line is shown; note the different scale for the age 5 graph. The particular years discussed in the text are indicated with asterisks rather than circles.

These comparisons suggest that, at the very least, the COHORT estimates of the age 3 and age 4 proportions for 1989 are unlikely to be accurate (with the age 3 proportion underestimated and the age 4 proportion overestimated), while the beach seine estimates are much more consistent with the behavior of the run between 1984 and 1990.

Table A2. Comparison of COHORT spreadsheet and USFWS beach seine estimates of Klamath River run sizes and run ratios, 1984-1990.

Run year	Age 2	Estimate Age 3	Age 4	Age 5	Total	Brood year	Ratios A3/A2	A4/A3	A5/A4
	Cohort								
1984	8,277	29,639	15,217	2,275	55,408	1980			0.061
1985	69,374	30,701	32,723	932	133,730	1981		1.10	0.002
1986	44,530	167,886	26,897	53	239,366	1982	3.71	0.88	0.001
1987	19,043	120,728	87,998	30	227,799	1983	2.42	0.52	0.014
1988	24,048	136,526	53,533	1,215	215,322	1984	2.71	0.44	0.060
1989	9,097	15,201	105,591	3,228	133,117	1985	7.17	0.77	0.001
1990	4,389	9,056	26,596	158	40,199	1986	0.63	1.75	
						1987	1.00		
Mean	25,537	72,820	49,794	1,127			2.94	0.91	0.023
SD	23,602	66,352	34,487	1,230			2.36	2.42	0.029
CV	0.92	0.91	0.69	1.09			0.80	2.65	1.27
	USFWS								
1984	7,203	22,163	24,934	1,108		1980			0.359
1985	34,369	50,817	39,584	8,960		1981		1.79	0.054
1986	54,815	154,152	28,245	2,154		1982	7.05	0.56	0.234
1987	23,919	87,475	109,799	6,606		1983	4.49	0.71	0.037
1988	13,135	106,800	91,297	4,091		1984	1.60	1.04	0.048
1989	6,390	51,383	70,951	4,393		1985	4.47	0.66	0.018
1990	4,824	11,457	22,632	1,286		1986	3.91	0.44	
						1987	1.79		
Mean	20,665	69,178	55,349	4,086			3.88	0.87	0.125
SD	18,517	50,277	35,306	2,905			2.02	1.94	0.139
CV	0.90	0.73	0.64	0.71			0.52	2.24	1.11

Run year 1985, age 2 and age 5

The discrepancies between the COHORT and FWS estimates of the proportions of age 2 fish and age 5 fish during this year are less important than the 1989 ages 3 and 4 discrepancies because these age classes contribute relatively little to the total run. The low number of fish in these age classes also means that a small number of errors in the other age classes can have a disproportionately large effect on the estimates for these age classes. The point for the 1989 estimates is the rightmost on the age 2 graph and the topmost on the age 5 graph. Errors in these two estimates are also not necessarily paired (as the 1989 age 3 and age 4 estimates are) because age 2 and age 5 fish are not likely to be mistaken for each other.

The situation for the age 2 proportion seems similar to that for the 1989 estimates: the COHORT proportion (51.9) is outside the observed range, 2.2 SDs above the mean. The USFWS proportion (25.7) is also extreme, but is less inconsistent with the values in other years, only slightly above their range, and 1.5 SDs above the mean. Neither estimate gives an A3/A2 ratio that is unusual, but the USFWS ratio (4.49) lies above the mean (3.88) while the COHORT ratio (2.42) lies below the mean (2.94), and a higher-than-average value better matches the 79% increase in the total run size between those two years.

The situation for the age 5 proportion in 1985 is less clear. The FWS estimate (6.7) is well outside the range of the other years, and is 2.0 SDs above the mean, while the COHORT estimate is not particularly unusual, so the latter might be preferable on grounds of consistency. However, the total run increased 141% between 1984 and 1985, and the very high FWS A5/A4 ratio matches this increase better than does the COHORT estimate (although the COHORT estimate, too, is at the high end of the range).

Consistency

Consistency in estimates of age composition is not necessarily desirable if the quantities that they estimate actually vary markedly. However, the errors introduced by an imprecise method are unlikely to reduce the apparent variability; they are likely simply to add another layer of variability instead. During the years in question, the total run increased in size, held steady, and then declined; although these changes were dramatic, they were not erratic. The impression that the FWS estimates are smoother and more internally consistent is borne out by comparisons of the coefficients of variation calculated across years, for the estimates of numbers of fish by age, proportions by age, and transition ratios. Without exception, every quantity has a lower CV with the FWS estimates than it does with the COHORT estimates. This pattern also holds for the actual proportion estimates for each age, which are not included in Table A2.

The beach seining and scale analysis were carried out during 1979-1983 as well, and it is possible to include those years in a comparison between the USFWS and the COHORT estimates. However, the COHORT estimates for those years were based on a different methodology, without the complicated multiplicative factor. Regardless, the above results remain essentially unchanged, and no new outliers are introduced away from the 45° lines. This lack of additional discrepancies suggests that the USFWS method is also consistent with the methods and findings used before (and, by extension, after) the period in question.

Finally, it may be worth noting that the approach that uses beach seining and scale analysis is relatively simple to understand, while the calculations in the COHORT spreadsheet are obscure even to those who have attempted to understand them.

Appendix 3. Description of adjustments in the size at age analyses

These adjustments were done to derive estimates of the mean length and standard deviation in length for months in which the sample sizes were too low to yield valid, independent estimates, and to smooth the trajectories in a few cases for which the independent estimates displayed implausible month-to-month variability.

Analysis by age and month

Age 2

- January-June means: linearly extrapolated from those of July through September
- January-June standard deviations: taken from that of July

Age 2-3

- October-April means: linearly interpolated between those of September and May (growth rate constant)
- September-April standard deviations: linearly interpolated between those of August and May (growth rate constant)

Age 3-4

- November-March means and standard deviations: linearly interpolated between those of October and April (growth rate constant)

Age 4-5

- November-April means and standard deviations: linearly interpolated between those of October and May (growth rate constant)

Age 5

- June-July means: linearly interpolated between those of May and August (otherwise would have had an anomalous decline between June and July)
- September-December means: taken from that of August
- August-December standard deviations: taken from that of July

Analysis by age, month, and release type

All ages and months

- XHAF means and standard deviations: taken as unweighted averages of IGHF and TRHF values.
- XHAY means and standard deviations: taken as unweighted averages of IGHY and TRHY values.

Age 2

- IGHF July and August means: linearly interpolated between those of June and September (to avoid a decrease in size between July and August)
- IGHF January-May means: linearly extrapolated from those of June and July (growth rate constant)
- IGHY, TRHF, TRHY, TRHZ January-June means: linearly extrapolated from those of July and August (growth rate constant)
- TRHZ June mean: linearly extrapolated from those of July and August (growth rate constant)
- TRHZ January-May means: linearly extrapolated at a growth rate of half that between June and August (to avoid unrealistically small fish during the early part of the year)
- All standard deviations: taken from the first reliable age 3 standard deviation (June for IGHF and TRHZ; May for IGHY, TRHF, and TRHY)

Age 2-3

- IGHF, IGHY, TRHY October-April means: linearly interpolated between those of September and May (growth rate constant)
- TRHF, TRHZ September-April means: linearly interpolated between those of August and May
- IGHF and TRHZ standard deviations through May: taken from that of June
- IGHY, TRHF, TRHY standard deviations though April: taken from that of May

Age 3

- IGHY September standard deviation: taken as average of August and October

Age 3-4

- All November-April means: linearly interpolated between those of October and May (growth rate constant)
- IGHF October-April standard deviations: linearly interpolated between those of September and May
- IGHY, TRHY November-April standard deviations: linearly interpolated between those of October and May
- TRHF October-May standard deviations: linearly interpolated between those of September and June
- TRHZ September-April standard deviations: linearly interpolated between those of August and May

Age 4

- TRHF August standard deviation: taken as average of July and September

Age 4-5

- All October-April means: linearly interpolated between those of September and May (growth rate constant)
- IGHF, TRHZ September-April standard deviations: linearly interpolated between those of August and May
- IGHY, TRHF, TRHY October-April standard deviations: linearly interpolated between those of September and May

Age 5

- All May-August means: all release groups lumped, with values taken from analysis by age and month
- All September-December means: taken from that of August
- All May-July standard deviations: all release groups lumped, so values taken from analysis by age and month
- All August-December standard deviations: taken from that of July

(Alternatively, the age 5 standard deviations might validly have been treated in a manner analogous to that of the age 2 standard deviations, by taking the last good age 4 value and extending it through age 5. Inspection of the graph of the proportion of legal-sized age 5 fish shows that the results of that approach would not have differed noticeably from those of the current approach. The current use of all release types together is also more consistent with the calculations for age 5 means.)

Analysis by age, month, and fishery

Age 2

- Troll June-September means: taken from those of sport
- Troll July-August standard deviations: taken from those of sport
- All January-May means: linearly extrapolated from those of June-July (growth rate constant)
- All January-June standard deviations: taken from those of July

Age 2-3

- All October-April means: linearly interpolated between those of September and May (growth rate constant)
- All September-April standard deviations: linearly interpolated between those of August and May

Age 3

- Sport July standard deviation: taken as average of June and August

Age 3-4

- Troll November-March means: linearly interpolated between those of October and April (growth rate constant)
- Sport October-April means: linearly interpolated between those of September-May (growth rate constant)
- All October-April standard deviations: linearly interpolated between those of September and May

Age 4

- Sport August standard deviation: taken as average of July and September

Age 4-5

- Troll November-April means: linearly interpolated between those of October and May (growth rate constant)
- Sport October-May means: linearly interpolated between those of September-June (growth rate constant)
- All October-April standard deviations: linearly interpolated between those of September and May

Age 5

- Sport June mean: taken as average of May and July (to avoid a decrease in size between May and June)
- Troll May-July standard deviations: taken from those of sport
- All September-December means: taken from that of August
- All August-December standard deviations: taken from that of July